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BULLETIN
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BULLETIN
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AUGUST, 1939

SUMMARY OF ROCKY MOUNTAIN GEOLOGY[1]

JOHN G. BARTRAM[2]
Tulsa, Oklahoma

ABSTRACT

The Rocky Mountain area of the western United States presents the most complete record on this continent of geologic events from Archean time to the present. Sediments from all the major periods are known somewhere in the region and the excellent outcrops have made possible their detailed examination. Many geologists have worked there and the literature is vast.

This paper is an attempt to summarize it all and to present a continuous story of geologic conditions and happenings in the Rocky Mountains from the pre-Cambrian to the Recent. This will be done with a series of paleogeographic maps and cross sections, and the stratigraphy will be described more fully than the structure. Four major events controlled the geology of the Rocky Mountain area.

1. The formation, in Algonkian time, of the Cordilleran geosyncline which extended from Utah to British Columbia and persisted in that position through all geologic periods to the end of the Upper Cretaceous.

2. The extension in the Pennsylvanian and Permian of the Arbuckle-Wichita-Amarillo line of mountains into New Mexico, Colorado, Utah, and Wyoming and their subsequent erosion and burial under Triassic and Jurassic sediments.

3. The uplift, in the Middle Triassic, of the Cordilleran land mass on the west and southwest which furnished sediments from those directions throughout the remainder of Triassic and all of Jurassic and Cretaceous time.

4. The extension eastward, at the close of the Upper Cretaceous, of the uplifted, folded, and faulted Cordilleran highland until the present Rocky Mountains were formed in the geosynclinal area and the sea was finally pushed from the interior of North America.

INTRODUCTION

This summary of Rocky Mountain geology is written to present a brief, but continuous story of geologic events from the Archean to Recent time. The Rocky Mountain country is so big, the geology so diversified with outcropping formations of every period, and so many articles have been published that it is difficult to get a bird's-eye picture of all that happened, and the causes. The writer had the good fortune to spend 16 years in the Rocky Mountains, associated with some of the ablest geologists in the region, and had access to many maps and

[1] Read before the Association at Oklahoma City, Oklahoma, March 22, 1939. Manuscript received, May 9, 1939. Published by permission of the Stanolind Oil and Gas Company.

[2] Division geologist, Stanolind Oil and Gas Company.

reports. Now, after leaving the Rockies, he wishes to present the entire picture as he sees it, or, in other words, to show the forest which may be hidden by the trees.

FIG. 1.—Map showing present outcrops of Archean rocks, mostly metamorphic in Rocky Mountain area.

The geologic happenings of several hundred million years could well require a series of papers, or even of books, but they are deliberately briefed to these few pages to make a short, concise story. They are presented with paleogeographic maps and cross sections.

ARCHEAN

The Archean of the Rocky Mountains consists of metamorphics, schists, gneisses, quartzites, and altered igneous rocks, which must have covered all the area, but are now exposed mostly in the cores

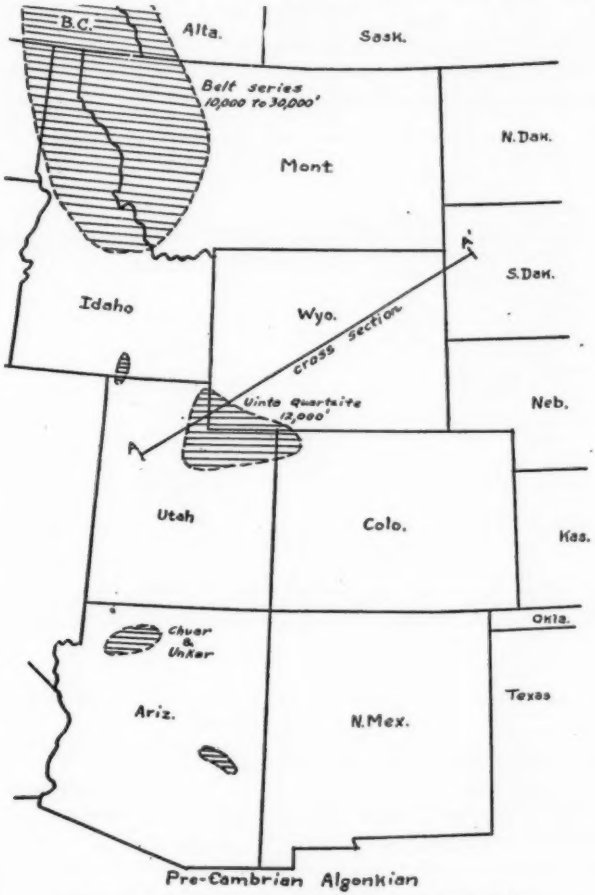

FIG. 2.—Map showing outcrops of Algonkian rocks. Line *AA'* is cross section shown in Figure 3.

of mountains in Wyoming, Colorado, and New Mexico. Farther west, they were buried too deeply under younger sediments to reach the surface during later uplifting, except in a few localities in Utah and in the Grand Canyon in Arizona. Where now seen, the top of the

Archean is generally smooth and well base-leveled. On these oldest rocks, some slightly less metamorphosed schists and argillites, assumed to be early Algonkian, are found in some places, but are not very extensive or important.

ALGONKIAN

The sedimentary record in the Rocky Mountains begins in the late Algonkian when thousands of feet of quartzite accumulated in northeastern Utah[3] and a greater thickness of shale and limestone in

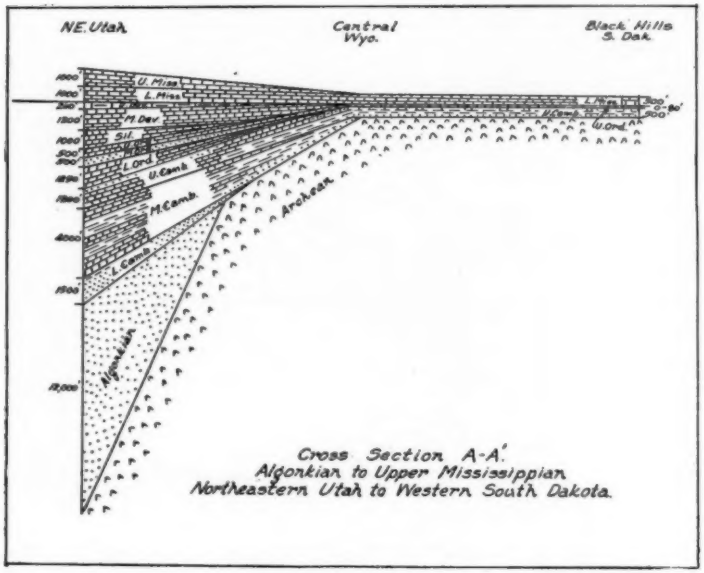

FIG. 3.—Cross section *AA'*.

western Montana,[4] Idaho, and Canada, and similar rocks at other places in the west. This appears to be the beginning of a great geosyncline that occupied a wide area through Utah, western Wyoming, Idaho, and western Montana from the Algonkian to the end of the Upper Cretaceous and received thick sediments during each succeeding period, mostly from a large and changing land mass somewhere on the west. This is generally called the Cordilleran geosyncline and the land mass, Cordilleran. The Algonkian rocks are 10,000–30,000 feet thick in the western geosyncline but thin within a short distance eastward and have not been reported in much of the area.

[3] J. W. Powell, *U. S. Geol. and Geog. Survey Terr.*, 2nd Div. (1878).

[4] Charles D. Walcott, *Bull. Geol. Soc. America*, Vol. 17 (1906).

CAMBRIAN

Over this wedge of Algonkian, there was deposited in Lower Cambrian time a similar layer of non-marine quartzite, 1,500 feet thick, in the geosyncline in northeastern Utah and southeastern

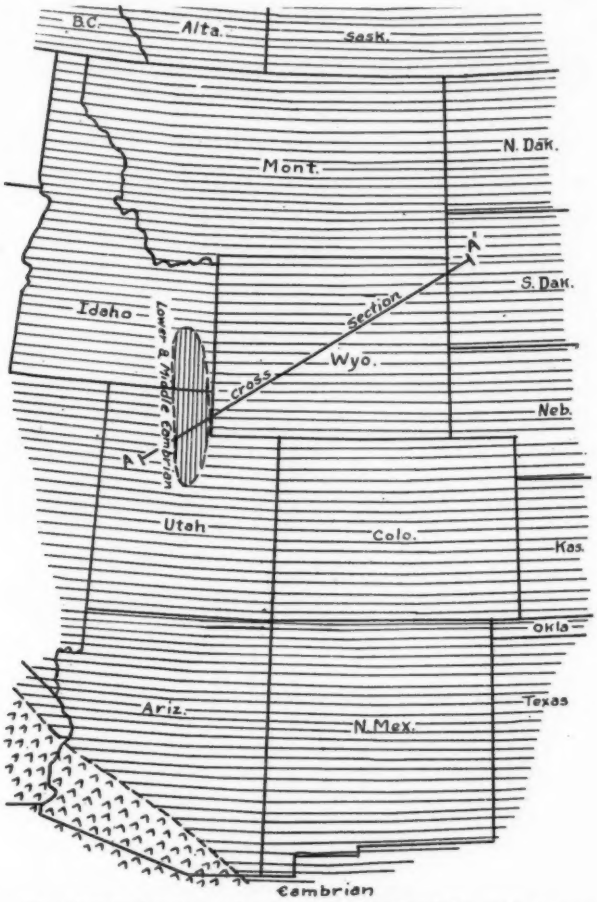

FIG. 4.—Map showing location of Lower and Middle Cambrian rocks in geosyncline and extent of Upper Cambrian in entire Rocky Mountain area.

Idaho,[5] but in Middle Cambrian the trough began to sink and a sea invaded the area. A series of shales and limestones, 4,000 feet in thickness, formed in the western trough, and younger beds succes-

[5] G. R. Mansfield, *U. S. Geol. Survey Prof. Paper 152* (1927).

sively overlapped older ones on the east until in the Upper Cambrian the sea expanded very much more and covered most of the west-central part of the United States. As the sea encroached, a coarse

FIG. 5.—Map showing areas now known to be covered with Ordovician rocks. Section *AA'* shown in Figure 3.

basal sandstone was deposited in an area extending from Arizona to Missouri and from Oklahoma to the Dakotas. Over the sandstone was laid a uniform series of greenish, glauconitic shales and limestones, 500–1,000 feet thick.

ORDOVICIAN

At the close of the Cambrian, the sea abruptly contracted and in the Lower Ordovician it occupied only the western geosyncline and an area in central and eastern Colorado that was the western end of the

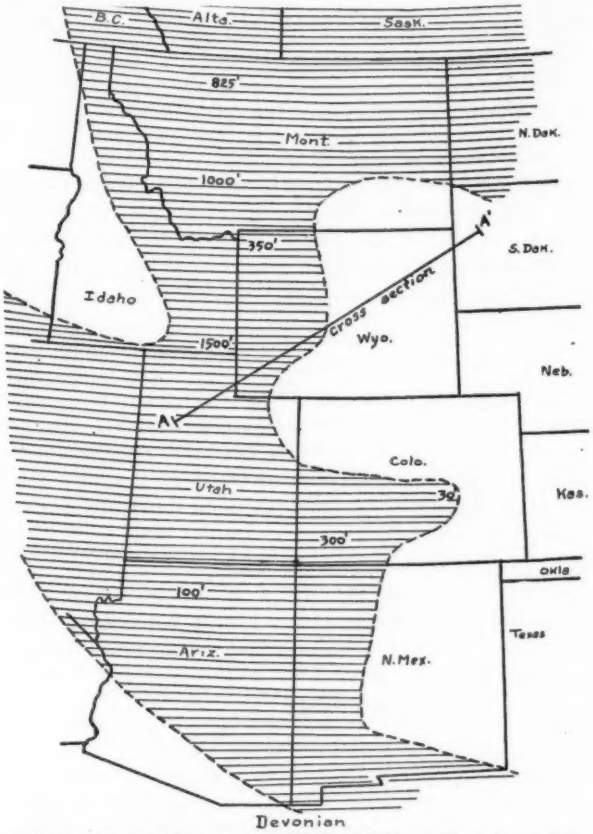

FIG. 6.—Map showing extent of Middle and Upper Devonian rocks. *AA'* is cross section of Figure 3.

Arbuckle-Wichita geosyncline of Oklahoma. Limestones equivalent to the Arbuckle of Oklahoma extend west to central Colorado but are only a few hundred feet thick.[6] Similar beds are 1,200 feet in thickness in the western geosyncline in Utah and Idaho, but seem to be absent farther north and east.

[6] A. E. Brainerd, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17, No. 4 (April, 1933).

In the Middle Ordovician, the seas remained small. Sandstones were deposited in the western trough and thin sandy equivalents of the Simpson formation of Oklahoma reached west to central Colorado. However, in the Upper Ordovician, the sea greatly expanded for the second time and limestones of Richmond age covered a wide area in a thin layer as far east as North Dakota and beyond. It may have been a continuous sheet, but is not so shown, since Ordovician rocks are now absent in much of Montana, eastern and southern Wyoming, western Colorado, and northern New Mexico and Arizona.

SILURIAN

Again, at the beginning of the Silurian, the sea withdrew, this time entirely to the Cordilleran geosyncline, and the only Silurian rocks are in the bottom of the geosyncline where 1,000 feet of dolomites of Niagaran age were deposited. The reported Silurian of other areas has later been placed in the Devonian.

DEVONIAN

In the Lower Devonian, the sea was still contracting, and there may be no Lower Devonian deposits even in the geosyncline, but in the Middle Devonian another important period of subsidence began. In the west, 1,200 feet of dolomites and limestones accumulated in Idaho and spread in a thinner sheet far to the southeast and northeast. These were followed by another relatively thin layer of Upper Devonian shales and limestones that graded into red beds and gypsum in northern Montana. Section AA' in Figure 3 crosses central Wyoming where the Devonian does not extend as far east as it does in Colorado and Montana. During the Devonian, eastern Wyoming and northern and eastern Colorado apparently did not receive any sediments, even though eastern Colorado had been low in the Ordovician and was to be low again in the Mississippian.

MISSISSIPPIAN

The expansion of the sea, which began in Middle Devonian, reached its maximum in Lower Mississippian (Keokuk-Burlington) time, and it once more covered the Rocky Mountain and Mississippi Valley regions. The Madison limestone and its equivalents were deposited in an even layer, about 500–1,000 feet thick, extending from Arizona to Canada and from Utah east for many hundred miles. In one locality, eastern Montana, it was thicker, 1,300–1,900 feet, where a new basin was forming. After Lower Mississippian, the sea contracted the third time and during Upper Mississippian remained only in the western geosyncline, the eastern edge of Colorado, and in east-

ern Montana. Limestones and calcareous sandstones formed in the western geosyncline, and limestones partly oölitic in eastern Colorado, but in eastern Montana[7] the Big Snowy group of Chester and Meramec age is 1,200–1,500 feet of shales, limestones, some sandstones, and

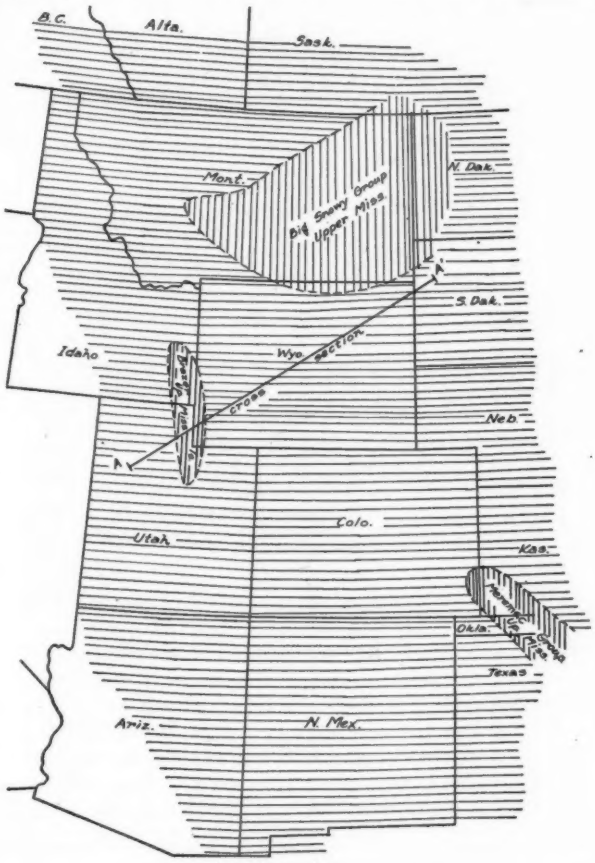

FIG. 7.—Map showing extent of Lower Mississippian (horizontal ruling) and Upper Mississippian (vertical ruling) in Rocky Mountain area.

even some salt beds along the North Dakota state line. This basin may be found to be even larger if more of the Pennsylvanian in northern Wyoming is later classified as Upper Mississippian.

[7] Harold W. Scott, *Jour. of Geol.*, Vol. 43 (1935).

PENNSYLVANIAN

The earliest Pennsylvanian rocks are marine shales and limestones, that gave little or no evidence of changed conditions, but soon a major change did occur, as the Arbuckle-Wichita Mountains of

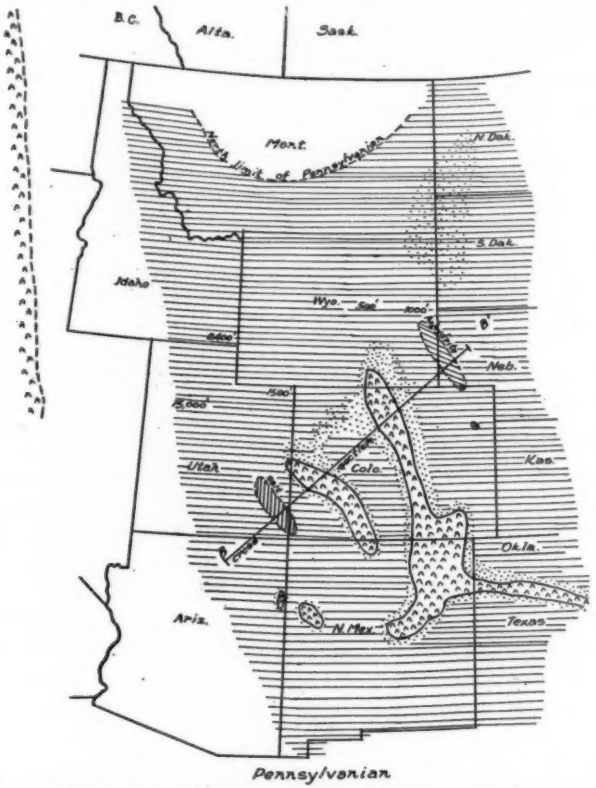

FIG. 8.—Map showing position of land areas (checked), alluvial clastics (dotted), marine sediments (ruled horizontally), and evaporites (ruled diagonally and vertically) during Pennsylvanian in Rocky Mountain region. Cross section *BB'* shown in Figure 9.

Oklahoma extended into New Mexico, Colorado, and the edges of Utah and Wyoming. Several large islands were formed in the sea which had again expanded over a wide area, but did not go far into Montana or the north. The outlines of the land masses on this map are largely copied from the fine work of Ross Heaton.[8] The uplifting

[8] R. L. Heaton, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17, No. 2 (February, 1933).

of the mountains also created some basins in which evaporites accumulated. In southeast Utah, thick salt occurs between marine shales and limestone; in central Colorado, between the land masses, marine Pennsylvanian shales and limestones are overlain by a thick gypsum bed that may be Permian, and in western Nebraska there are salts and anhydrites in both the Pennsylvanian and Permian. The uplifted land masses were rapidly eroded through the sediments into the pre-Cambrian basement rocks and coarse arkoses piled up in alluvial fans on the flanks and thinner sandstones wedged into the marine shales and limestones. On the east, in Colorado and Wyoming,

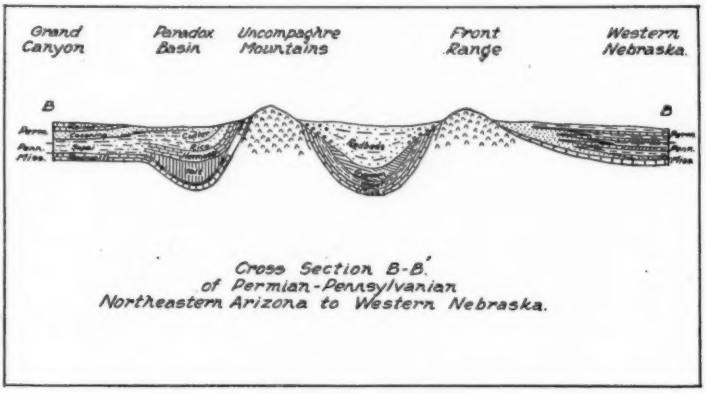

FIG. 9.—Cross section *BB'*.

these sandstones did not spread far, but, on the north, part of the Pennsylvanian is white sandstone, the Tensleep. In the Black Hills region of South Dakota the Pennsylvanian is sandy and red, and those sandstones probably did not come from Colorado. The geology of the Pennsylvanian is not yet fully known, although much has been learned of that region in the last few years. While mountains were formed and eroded in Colorado, the western geosyncline in Utah and Idaho remained about the same, except that it was probably deeper, as the Pensylvanian is reported to be more than 15,000 feet thick southwest of Salt Lake City.

PERMIAN

The change from Pennsylvanian to Permian is not marked by any sharp break in the Rocky Mountains and is still uncertain in many places. The Colorado land masses were uplifted more or at least

eroded more, and coarser arkoses and conglomerates accumulated on their slopes in central Colorado and eastern Utah. They graded into red beds in all directions and the red beds in turn graded into

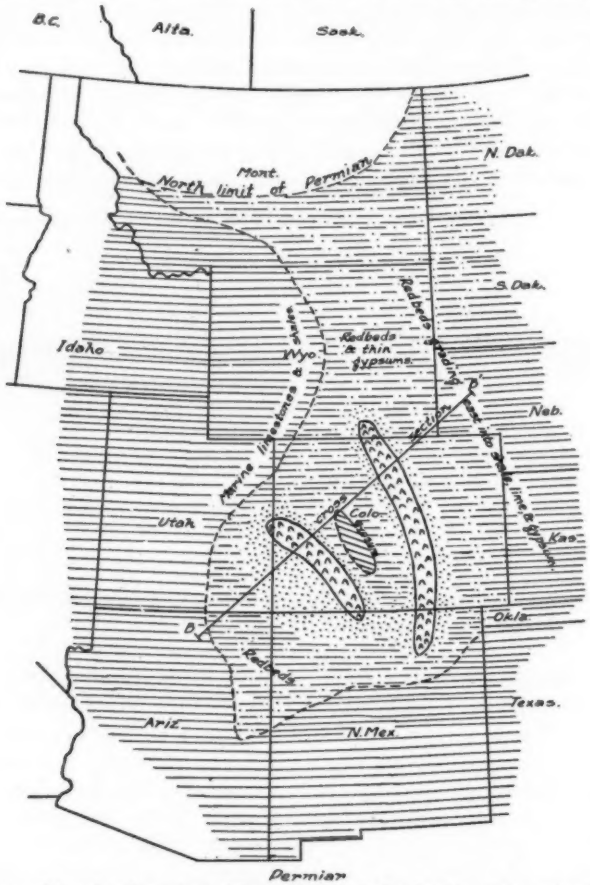

FIG. 10.—Map showing extent of Permian rocks in Rocky Mountain region. Land areas shown by checks and alluvial clastics by dots.

marine limestones and shales to the west, south, and east, but at the north, in northern Montana, the Permian was absent, as were also the Pennsylvanian and Triassic. It appears now that most of the red Permian sediments in the Rocky Mountains came from the local land masses. As previously stated, there were evaporite basins in central

Colorado and western Nebraska and thin gypsums are common in the red beds. On the west in the Cordilleran geosyncline, thick limestones still accumulated as they had in each previous period.

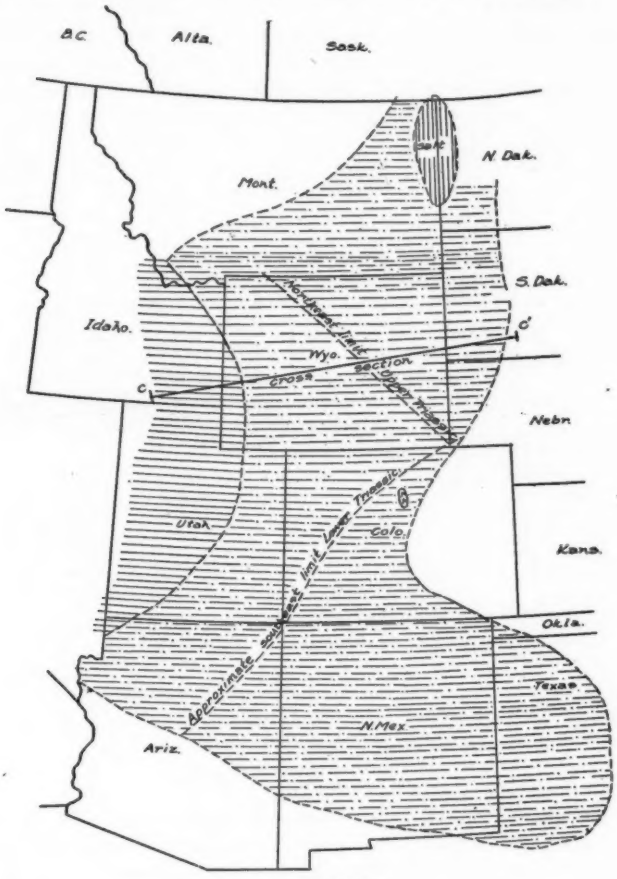

FIG. 11.—Map showing extent of Triassic sediments. Small land area shown in north-central Colorado.

TRIASSIC

By Triassic time, the Colorado land masses were mostly eroded and buried in their own débris and were no longer of importance. Throughout the Lower Triassic, the sea persisted in the western

geosyncline and thick marine shales and limestones were deposited but east of the area of limestones an even layer of bright red sandy shales was spread over Wyoming, eastern Utah, northern Arizona, and northwestern Colorado. These Lower Triassic "redbeds" are not found southeast of the line shown in Figure 11. There has been some argument about their source, but the writer believes they came from the south and southeast and are reworked Permian "redbeds" eroded from Texas and Oklahoma and redeposited farther northwest.

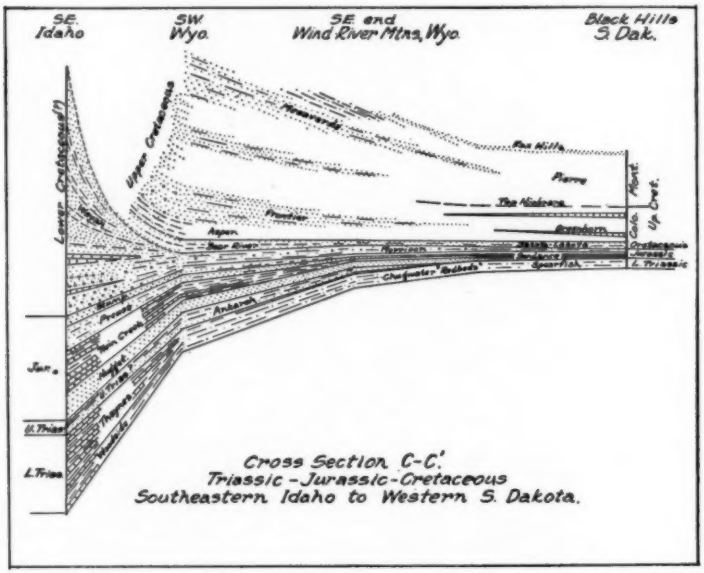

FIG. 12.—Cross section *CC'*.

The beginning of the Upper Triassic is another important date in Rocky Mountain geology, since at that time coarser sediments began coming into the geosyncline from the west and continued to come in increasing quantities through Jurassic and Cretaceous time. Previously, the Cordilleran land mass west of the geosyncline was very indefinite and its shore line uncertain, but now the land mass had been uplifted and the western shore line was close. During the Upper Triassic, sandstones mixed with limestones in the geosyncline and spread east to central Wyoming as a thin layer of red beds. Farther southeast, red beds continued to come into New Mexico, Colorado, Arizona, and Utah from the south, southeast, and southwest, and

even covered northwest Texas, but did not go as far north and northeast as had the Lower Triassic.

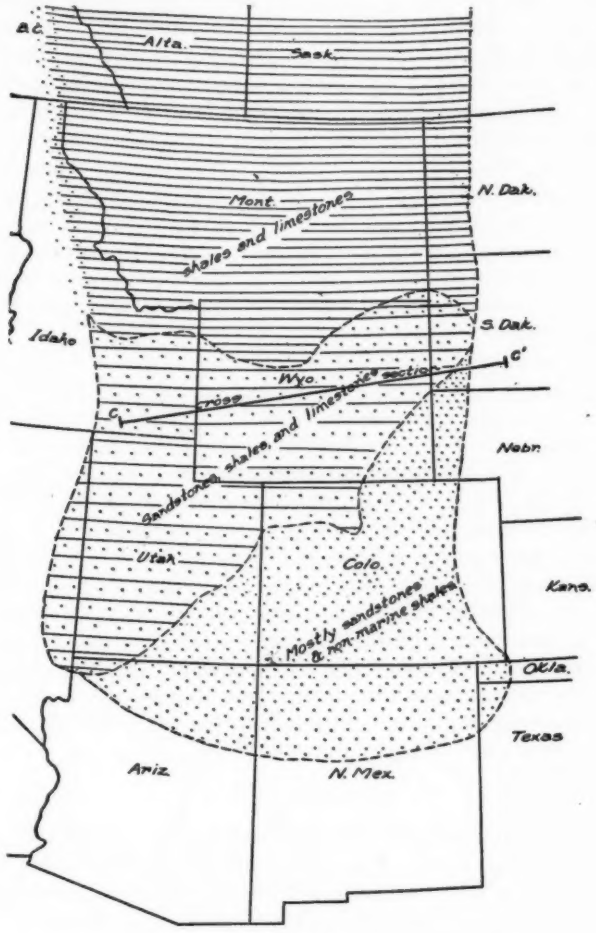

FIG. 13.—Map showing area covered by Jurassic rocks.

JURASSIC

The Jurassic brought more uplift of the Cordilleran land area and more coarse sediments from the west. Sandstones spread far toward the east and alternated with shales and limestones deposited during

two invasions of the sea. The earliest Jurassic is white to reddish cross-bedded sandstone, 2,000 feet thick in southwest Utah and extends northeast to South Dakota and east to the edge of Oklahoma. This basal sand was not deposited over the entire area, and is absent in western and central Colorado, probably because that country was too high to be covered by it. The first marine invasion was the largest and its shales and limestones are found from Utah north far into Canada. In northern Montana, it was the first formation deposited since Lower Mississippian, and Jurassic shales lie on Madison (Lower Mississippian) limestone. These Jurassic marine shales are thick in the western geosyncline but are only 50–300 feet thick in much of the wide area east and north. They are overlain by the next sandstone-red-bed tongue from the west, which left another thick sandstone in Utah and covered most of western and central Colorado. It also spread to South Dakota.

The second invasion of the Jurassic sea covered a much smaller area than the first and was limited to Utah, Wyoming, and northwestern Colorado. Its shales grade west into sandstones, which were the lower members of a wedge of sandstones, red shales, and a few limestones that accumulated 12,000–15,000 feet thick on the east flank of the Cordilleran land mass. The great Idaho batholith was forming, the shore line was crowding east and coarse sediments poured over the old geosyncline. Finer shales and sandstones were washed far east over the entire Rocky Mountain region as a flood plain series of variegated rocks, which are now the Morrison formation 200–500 feet thick. It is mostly Jurassic in age but strata similar in character are also Lower Cretaceous in eastern Colorado and Montana. The thick series in the west has been placed questionably in the Lower Cretaceous, but the Morrison is probably the thin eastern equivalent of much of it.

UPPER CRETACEOUS

Over this flat flood plain, the sea came into the Rockies once again at the beginning of the Upper Cretaceous. In this final invasion, it covered more country than at any time since the Lower Mississippian and received more sediments than in any other period. It reached from New Mexico far north into Canada and from Utah to Iowa, and, in most of that wide area, the Upper Cretaceous sediments, principally dark shales, average at least 5,000 feet in thickness. As the sea encroached over the Lower Cretaceous-Jurassic flood plain it reworked the uppermost strata to form a basal sandstone, the Dakota. On top of that, settled the great mass of dark shales, very siliceous in the

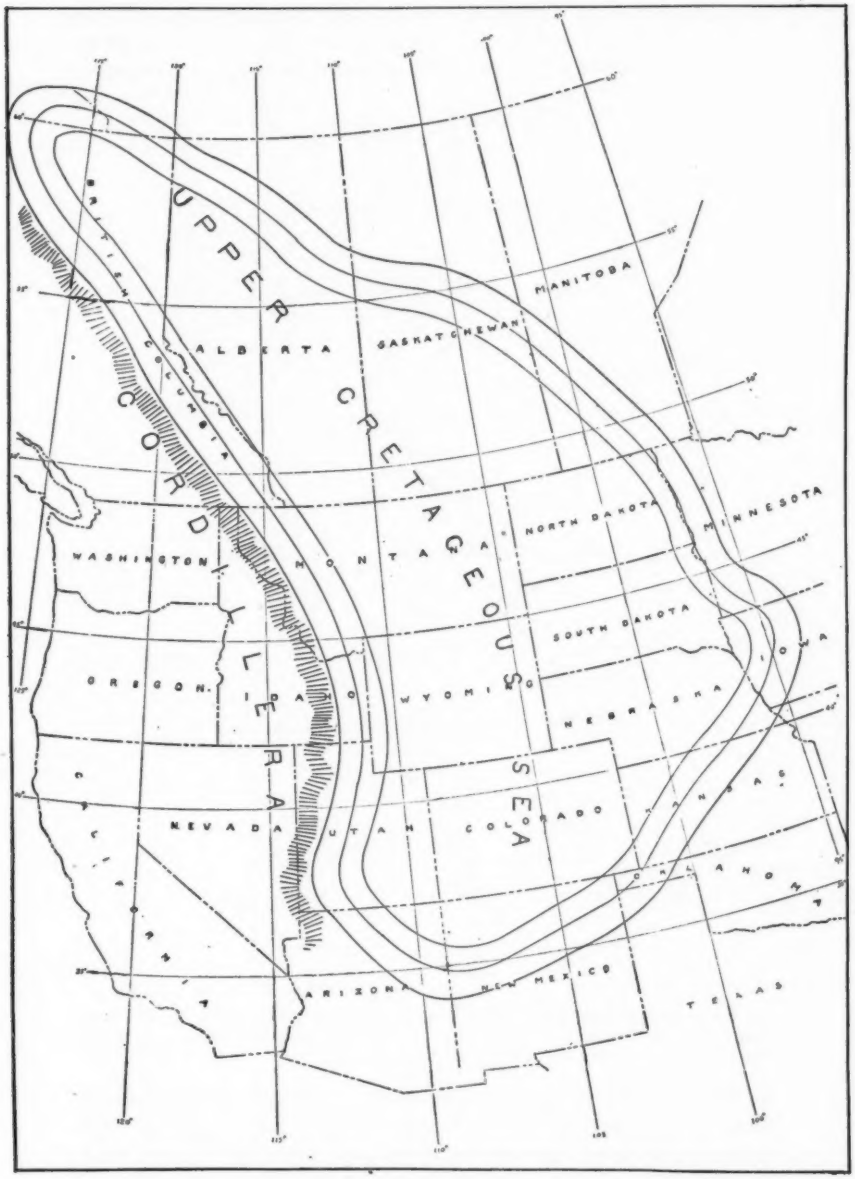

FIG. 14.—Map of Rocky Mountain and Great Plains areas to show extent of Upper Cretaceous sea in United States and Canada and eastern edge of Cordillera.

lower part, due to deposition of silica that had been dissolved from volcanic ash blown and washed into the water from western volcanoes. This sea was quiet on the east and several limestones were deposited

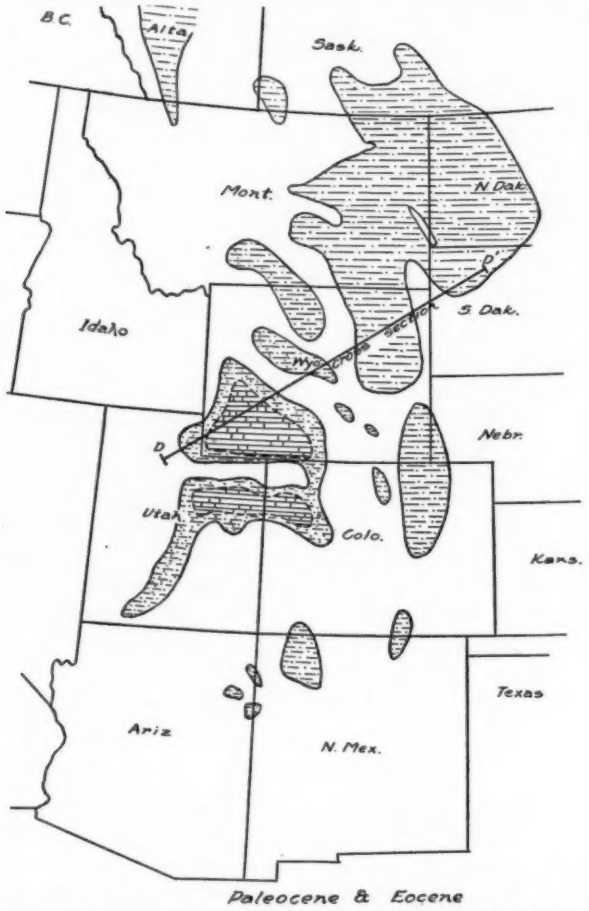

FIG. 15.—Map showing location of Paleocene and Eocene rocks in Rocky Mountain region. Ruled and blocked areas in southwest Wyoming, northeast Utah, and northwest Colorado are Green River lake beds.

in the Great Plains area and at one time the limestones extended a long distance west. All through the Upper Cretaceous, coarse sediments piled[9] up on the western shore, and, three times, great sand-

[9] John G. Bartram, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 21, No. 7 (July, 1937).

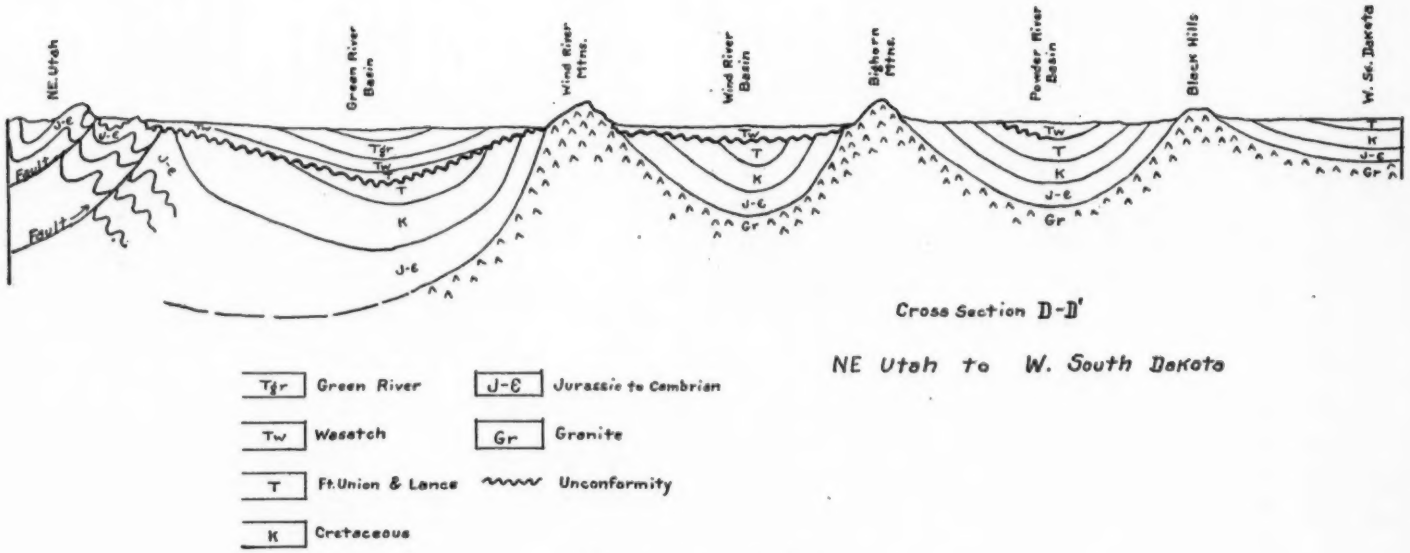

FIG. 16.—Cross section *DD'*.

stone tongues or deltas swept east into the area of shale deposition. Near the close of the Upper Cretaceous, mountain building was active in the west, the shore line had been crowded east to the Idaho-Wyoming boundary, and volcanoes were pouring out igneous material in northwestern Wyoming and southwestern Montana.

PALEOCENE AND EOCENE

The uplifting forces finally pushed the sea from the Rocky Mountains and flood-plain sediments, eroded from the rising western country, washed east and formed the Lance and Fort Union formations of Paleocene and Eocene age in central and eastern Wyoming, Montana, and the Plains states. The mountain folding was continually moving east, but it was not until after the deposition of the Fort Union, that the last major folding occurred, and all the eastern mountains were uplifted. The folded western country had been eroded for some time but after the Fort Union in early Eocene all the Rocky Mountain ranges were being eroded and the older formations truncated. The resultant débris was washed into the intermontane basins where it was deposited as the Wasatch formation, unconformable on all older formations. In Wyoming, Utah, and Colorado some of the basins had no outlets and fine shales, oil shales, and limestones were laid down in fresh-water lakes, but graded laterally into Wasatch alluvial sediments.

These conditions are shown in the somewhat idealistic cross section of Figure 16. The western geosyncline had been folded and thrust-faulted into large mountain ranges, and the Upper Cretaceous and all older formations truncated. The Eocene Wasatch red and variegated shales and sandstones overlapped unconformably all older beds. If any rocks equivalent to the Lance and Fort Union are present in this region, they are probably coarse sandstones and conglomerates found above the great unconformity. Farther east in the Green River basin, it is suspected that the unconformity is in the Lance-Fort Union and that it is rising in the section, for in the Wind River basin it is above the Fort Union and the Wasatch overlaps the Fort Union and all older formations. Still farther east, the unconformity fades until it is almost imperceptible on the east side of the Powder River basin. East of the Black Hills no Wasatch is now known.

The early geologists in the Rocky Mountains did not realize the progressive nature of the folding and assumed that it all occurred in a fairly short period of compression and mountain building, the so-called Laramide revolution. The major unconformity was believed to be everywhere at the same place in the section and should be the

Cretaceous-Eocene boundary. That caused much confusion and argument for a long time.

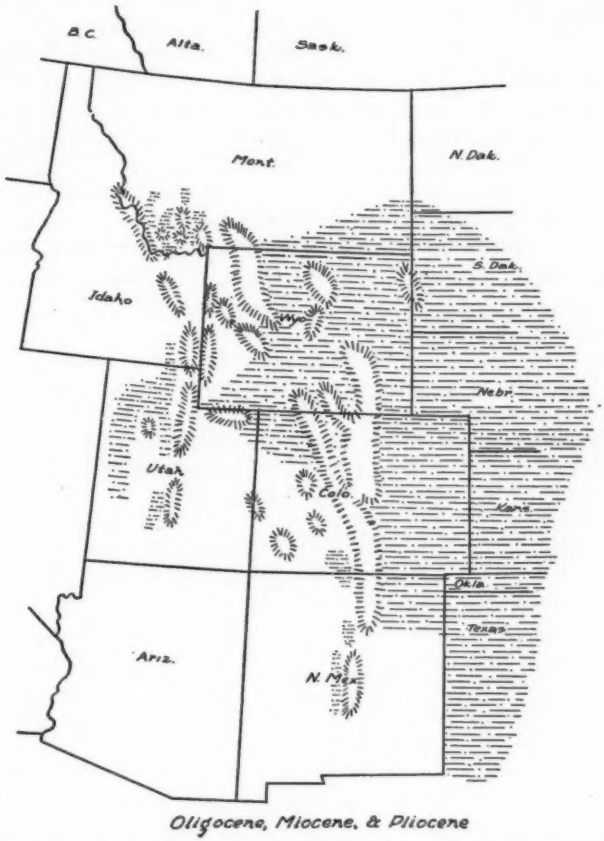

FIG. 17.—Map showing extent of post-Eocene deposits in Rocky Mountain region. Hachured areas are mountains that were being eroded.

OLIGOCENE, MIOCENE, AND PLIOCENE

With the Eocene, ended the most important events in the Rockies. No more ranges were pushed up, and the only uplifting was of large plateaus or entire ranges, probably by isostatic adjustments. The western country was no longer under compression, but under tension which caused large normal faults and resultant grabens in Utah,

Idaho, and New Mexico. Volcanoes were active in the northwest and during Oligocene, Miocene, and Pliocene, volcanic material and other sediments from the large ranges washed eastward in another flood plain that buried the Wasatch basins, the foothills, and some of the lower ranges. On that plain, the present drainage pattern developed and the rivers at a later date stopped aggrading and to the present have been mostly degrading their valleys. In the west, the same Tertiary sediments filled the sinking grabens, in which formed Lake Bonneville, the predecessor of Great Salt Lake, and other lakes.

In the Pleistocene, the Rocky Mountain area was too high for the Continental ice sheet and the glaciers did not invade beyond central Montana, but they did block the Missouri River's channel to Hudson Bay and force it to cut a new course east to the Mississippi River. Mountain glaciers were widespread in the higher mountains and some still persist in reduced size to-day.

Thus ends the story of a great geosyncline that lasted from the Algonkian to the Upper Cretaceous and finally was compressed and lifted entirely above the sea. Conditions have greatly changed, the seas are far away, the geosynclines are on the Pacific Coast and along the Gulf of Mexico, and perhaps the Rocky Mountains will now be a positive land mass for untold ages. Who knows?

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 23, NO. 8 (AUGUST, 1939), PP. 1153-1177, 13 FIGS.

CONTRIBUTION TO JURASSIC STRATIGRAPHY OF ROCKY MOUNTAIN REGION[1]

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ABSTRACT

More than 75 sections of the Jurassic beds were measured along the eastern flank of the Rocky Mountains in Colorado and New Mexico and in the region comprising northern Utah and adjoining parts of Wyoming and Idaho. These, combined with measurements by other geologists, are here used in correlation sheets to show that the basal sandstone of the "Jurassic" of northern Colorado is probably partly Entrada and partly Upper Triassic; that the latter grades into red beds southward and the former continues into New Mexico where it is identical with the so-called Wingate; that it does not extend westward to the Arizona line but can be correlated with the lower LaPlata of the San Juan Mountains in Colorado.

The true Wingate of the Zuni Mountains grades marginally into red beds and may be of Upper Triassic age.

Type Nugget sandstone of southwestern Wyoming is equivalent to the Navajo of Utah and Arizona but the so-called Nugget of northwestern Colorado is Nugget and Entrada separated by a thin remnant of the Carmel formation.

INTRODUCTION

The equivalencies of certain Jurassic formations in the Rocky Mountain region have, until comparatively recently, been accepted as authentic on the basis of general lithologic and stratigraphic characteristics. In some instances almost identical sequences of strata were quite naturally taken to be equivalent but more detailed study has subsequently proved the correlations erroneous.

Careful and detailed work on the part of members of the U. S. Geological Survey and others has, in late years, established certain relationships which in many instances marked a decided departure from accepted correlations of many years standing. Thus, the relationships of the Jurassic formations had been well established between Arizona, Utah (except the northern part), western Colorado, and northwestern New Mexico. Correlations had not been so well established between southwestern Wyoming, southeastern Idaho, northern Utah, and northwestern Colorado, nor between eastern Colorado, northeastern and northern New Mexico, and southwestern Colorado. Locally, however, the formations had undergone a thorough study.

The writer has attempted to follow out the Jurassic formations from the Colorado-Wyoming line south along the eastern foothills of the Rocky Mountains to Las Vegas, New Mexico, and from there to the Canadian River. Studies had previously been made in southwestern Colorado, in the Purgatoire uplift of southeastern Colorado,

[1] Manuscript received, May 20, 1939.

[2] Geologist, U.S. Bureau of Reclamation.

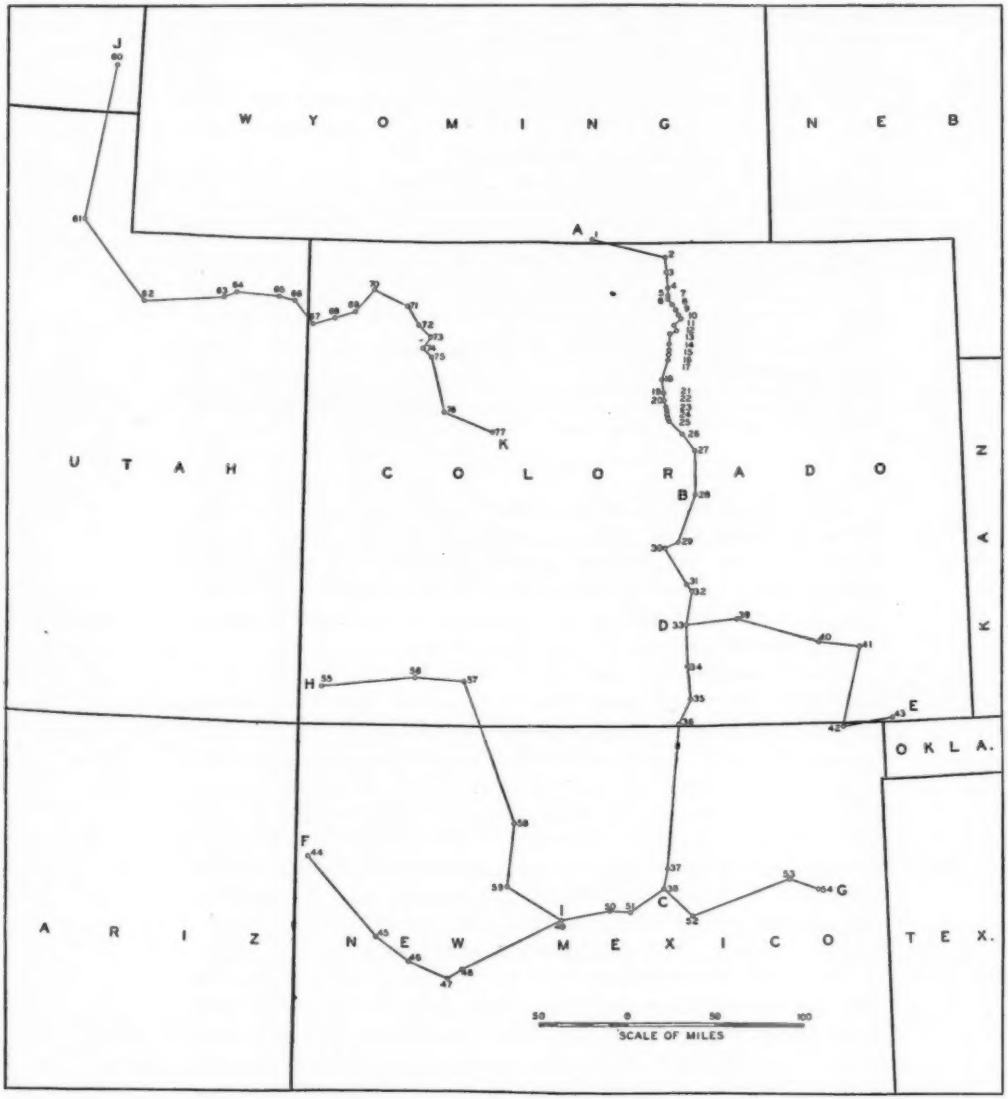


FIG. 1.—Index map showing lines of sections.

in the Cimarron valley of northeastern New Mexico and, more perfunctorily, in the remainder of northern New Mexico. The Jurassic and related formations were also studied beginning at the type locality of the Nugget sandstone, southwestern Wyoming, and following it through southeastern Idaho into northern Utah and east along the Uinta Mountains into northwestern Colorado.[3]

NORTHERN FRONT RANGE, COLORADO, TO LAS VEGAS, NEW MEXICO

The principal object of the study in this area was to trace southward the massive sandstone member at the base of the Morrison formation of northern Colorado and to determine, if possible, its relationships to dissimilar beds which occur farther south at an apparently identical stratigraphic position; also ultimately to determine the relations of this lithologic unit to a similar massive sandstone in northern New Mexico. A secondary, but no less interesting objective in the progress of this work, was to note local characteristics and lithologic changes in the lower Morrison beds, exclusive of the basal sandstone, and to observe the stratigraphic relations of both to the underlying formations.

Reeside[4] correlates the basal sandstone of the Morrison in northern Colorado with the Entrada sandstone, a well defined member of the very complete Jurassic section in the San Rafael Swell, Utah.[5]

There seems little doubt that the so-called "Sundance sand" of Wyoming, at the base of the Sundance formation, is Entrada or at least that the Entrada is represented in it even though the sandstone may in some localities contain representatives of the Nugget sandstone or the Upper Triassic or both.

The Lykins formation, as originally defined,[6] included all of the beds between the Morrison and Lyons formations. The type section of the Morrison contains no basal sandstone but the "Doctor Bond" sandstone or Entrada sandstone of this paper was included in the

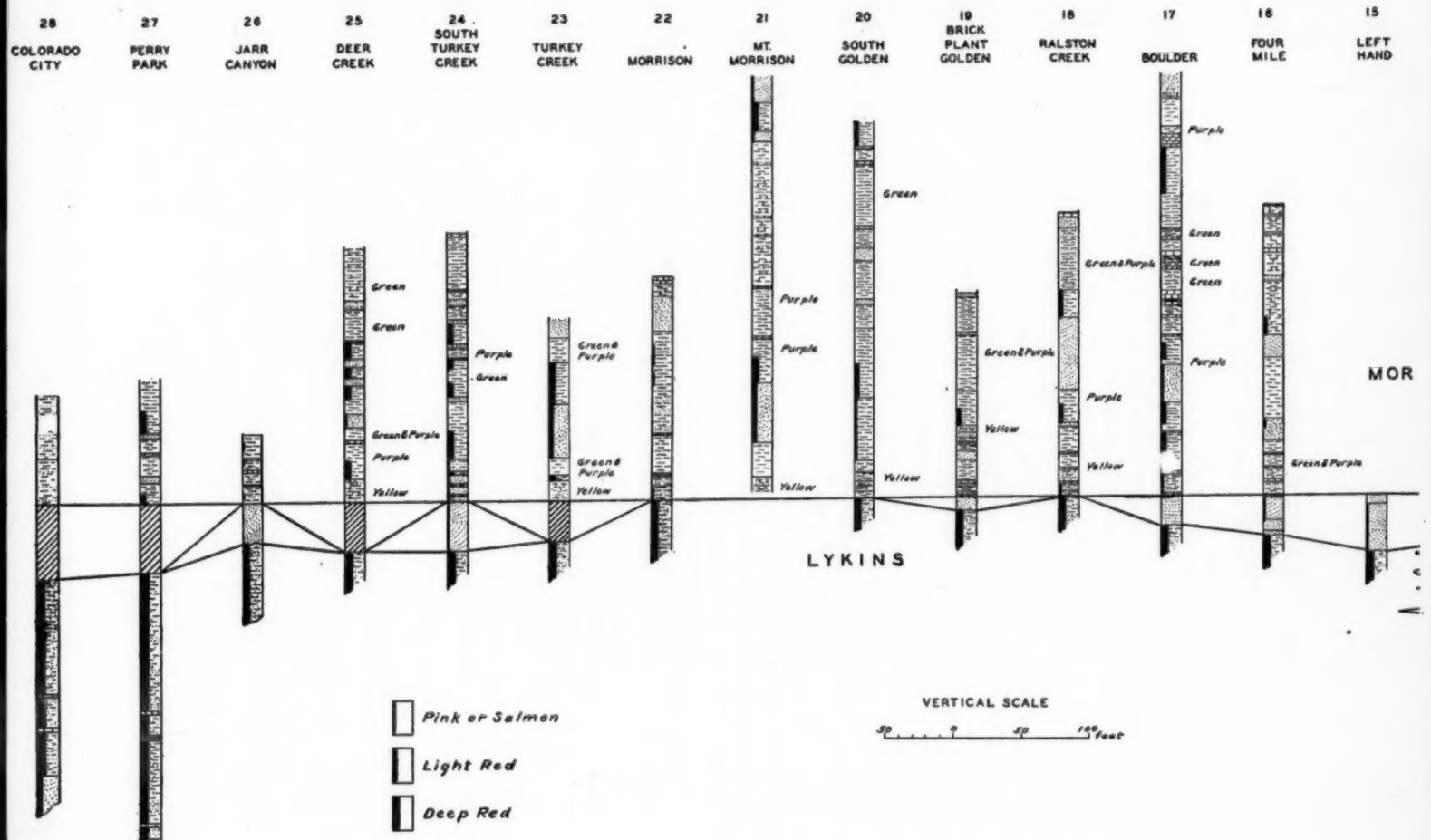
[3] This work was made possible by a grant-in-aid from the National Research Council.

[4] John B. Reeside, Jr., "Supposed Marine Jurassic (Sundance) in Foothills of Front Range of Colorado," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 9 (September, 1931), p. 1102.

A. A. Baker, C. H. Dane, and J. B. Reeside, Jr., "Correlations of the Jurassic Formations of Parts of Utah, Arizona, New Mexico, and Colorado," *U. S. Geol. Survey Prof. Paper 183* (1936), p. 28.

[5] James Gilluly and John B. Reeside, Jr., "Sedimentary Rocks of the San Rafael Swell and Some Adjacent Areas in Eastern Utah," *U. S. Geol. Survey Prof. Paper 150* (1928), p. 62.

[6] N. M. Fenneman, "Geology of the Boulder District, Colorado," *U. S. Geol. Survey Bull. 265* (1905), p. 24.



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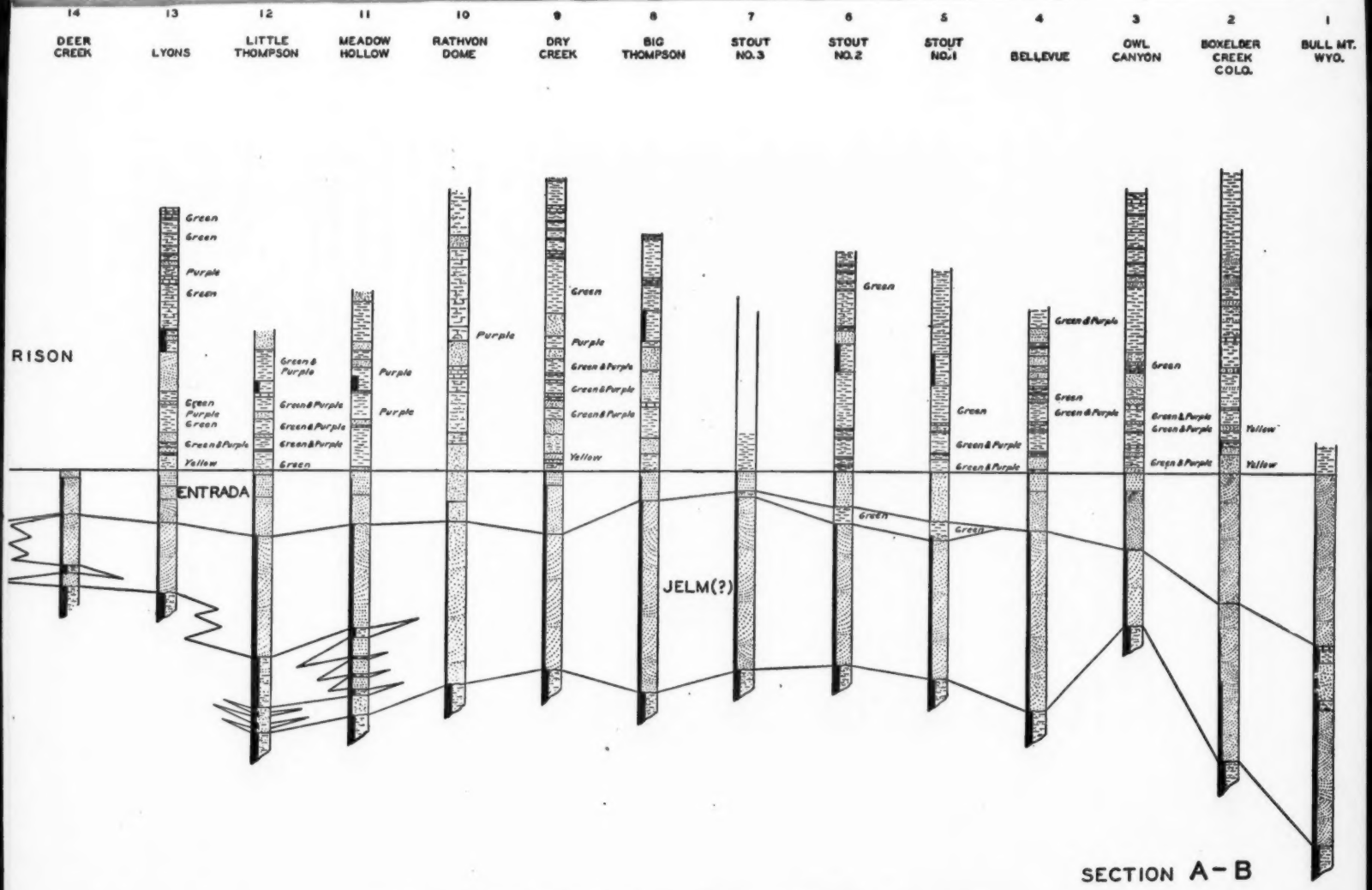

FIG. 2.—Section sheet *A–B* from Bull Mountain, Wyoming, to Colorado City, Colorado.

Morrison by Fenneman[7] in the Boulder district. In the northern part of the state, Butters[8] described the massive sandstone at the base of the Morrison and correlated the upper part with Darton's Sundance of Wyoming. He states that it did not extend south of the Cache La Poudre River. He evidently placed the lower part of the massive sandstone in the Lykins.

It now appears that these sandstones may be correlated fairly conclusively with formations of known Jurassic and Upper Triassic age.

Section No. 1 at Bull Mountain, Wyoming (Fig. 2), shows nearly 300 feet of massive sandstone the upper half of which is quite different in appearance from the lower half and is separated from it by a layer of limestone and red shale. The entire thickness of the sandstones is undoubtedly Knight's Jelm[9] formation, but it seems quite likely that the Entrada is represented in the upper part.

A considerable distance separates the Bull Mountain section from that at Boxelder Canyon, section No. 2 in northern Colorado, but the sections are very similar as are also the next two, Nos. 3 and 4, at Owl Canyon and Bellevue. The sandstone at these localities is 120 and 220 feet thick, respectively. It is divisible into two parts (Fig. 3) with a definite wavy contact between (Fig. 4). Both parts are marked by typical eolian cross-bedding. The upper 15 feet is very light pink and is more evenly bedded, due probably to reworking by the waters of the Morrison lake after eolian deposition had ceased. The remainder of the upper 69 feet of the sandstone is massive and pink or salmon-colored. The tangential cross-bedding is very evident although the sandstone does not weather out in layers or ledges. The lower foot contains small pebbles. The lower 60 feet of the sandstone, which will hereafter be designated Jelm (?), is darker in color (light red), is more thinly bedded, and weathers out in small ledges. The upper 2 or 3 inches are shaly and purplish in color.

At Bellevue the upper part, which is here correlated with the Entrada, has thinned and the lower part thickened. In the three sections 1, 1½, and 2½ miles, respectively, south of Stout, a break of greenish sandy shale appears between the Entrada and the Jelm (?). At Stout No. 1 there is a gradation from shale into the Jelm (?), but the upper surface of the shale makes a rough wavy contact with the

[7] *Ibid.*, p. 26.

[8] Roy M. Butters, "Permian or 'Permo-Carboniferous' of the Eastern Foothills of the Rocky Mountains in Colorado," *Colorado Geol. Survey Bull. 5*, Pt. 2 (1913), p. 70.

[9] S. H. Knight, "Age and Origin of the Red Beds of Southeastern Wyoming," *Bull. Geol. Soc. America*, Vol. 28 (1916), p. 168.

overlying Entrada. The upper part of the shale is gypsiferous and reddish to purple in color. The shale member persists for 1½ miles but at Stout No. 3 has thinned to 5 feet and is very sandy.

Southward for 15 miles the section is very similar to that north of Stout. The break between the two sandstone members is not always evident, mainly on account of incomplete exposure.

Near Stout and also at Big Thompson River two or three red shale streaks appear in the base of the Jelm (?). At Meadow Hollow

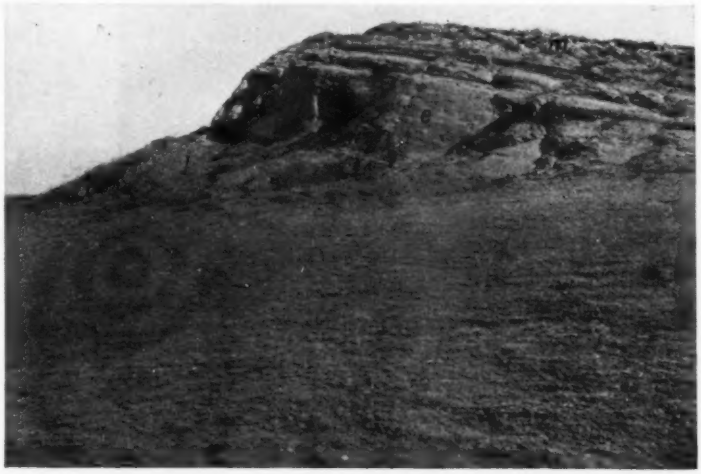

FIG. 3.—Section at Owl Canyon, *m*, Morrison limestone; *e*, Entrada sandstone; *j*, Jelm (?) formation; *l*, Lykins formation.

many of these red-bed streaks are evident in this member. They increase in number and thickness southward until at Left Hand Creek, north of Boulder, the entire member has merged into the typical red beds of the Lykins formation. If, as seems likely, the lower member of the massive sandstone can be correlated with the Jelm of Wyoming, the evidence seems to point to the supposition that the Upper Triassic is represented in the upper part of the Lykins. This, however, as will be seen later, must be true only in the northern part of the state.

The Entrada persists southward as far as Boulder where it is known as the "Doctor Bond" sandstone. Farther south it occurs only as lenses, one of which shows in the section at the brick plant north of Golden. Its unconformable contact with the Lykins is very evident at Four Mile. At Ralston Creek and from the south Golden section to

Morrison, the Morrison shales lie directly on the Lykins red beds.

At Turkey Creek, south of Morrison, bedded gypsum 30 feet thick appears in the base of the Morrison formation. It occurs again at Deer Creek and at Perry Park and continues to Colorado City and southwest nearly to Canon City. Southward from that locality no more gypsum occurs except in southeastern Colorado.

FIG. 4.—Near view of Entrada-Jelm (?) contact at Owl Canyon.

The Entrada exists as lenses in the South Turkey Creek and Jarr Canyon sections and also in numerous other localities, more notably between Golden and Morrison and just north of the Colorado City section.

Along the Front Range none of the sections contains both the sandstone and the gypsum. The inference is that in this region the Entrada existed only as scattered dunes which were later submerged in the early stages of existence of the Morrison lake. The gypsum, together with thin intercalated beds of greenish gray shale, was deposited around the sand lenses. Gypsiferous, earthy appearing

shales occur in the next succeeding stage of deposition and overlie the sandstone or the gypsum in all of the sections south of and including Ralston Creek. Many of them contain yellow limy shales or limestone, the latter resembling spring deposits. This part of the Morrison is definitely unlike the typical marls and limestones of the upper Morrison of this and other localities.

The section at the gypsiferous horizon changes more rapidly than is indicated by the chart (Fig. 2). Sections 23 and 24 at Turkey Creek and South Turkey Creek are less than 1½ miles apart. Three other

FIG. 5.—View near Big Thompson River showing streaks of red shale in base of Jelm (?) formation. *j*, Jelm (?) formation; *r*, red beds.

sections between them were measured. At the northern one the gypsum of the Turkey Creek section is entirely replaced by vari-colored sandy shales and sandy limestones, all of earthy and gypsiferous appearance. In the next section toward the south these beds alternate with beds of gypsum, and in the third they are almost entirely replaced by gypsum. Section 24, adjoining, has only the sandstone.

The gypsum of this locality and that of southeastern Colorado and northern New Mexico (Todilto) are considered to have been deposited as evaporation products in marginal areas of the marine Jurassic depositional basin of Curtis age.

Section sheet *B–C* (Fig. 6), which is a continuation of sheet *A–B* (Fig. 2) shows the gypsum playing out between Eight Mile and Canon City. Neither the Entrada sandstone nor the gypsum is present in the Canon City or the North Creek section. A greenish white, even bedded sandstone overlies the Lykins formation at these localities, but it is similar in lithology to other sandstones which alternate with conglomerates higher in the Morrison and is therefore placed in that formation. Except for one bed of conglomerate in the Morrison at Beulah, the Canon City and North Creek sections are the only ones which contain conglomerates. These conglomerates are unlike those of the Fountain formation and are separated by greenish to reddish sandstones, often shaly. The Canon City section contains an aggregate of 60 feet of conglomerate and the North Creek section, more than 100 feet. A 6-inch lens of conglomerate occurs at the base of the Morrison at North Creek. The 34-foot bed of conglomerate next above is light red in color and contains pebbles of gray limestone, quartzite, and pre-Cambrian rocks some of them 2 inches in diameter. Higher beds of conglomerate are similar. These occurrences indicate close proximity to the low land area on the west which existed during Morrison time.[10]

At Beulah the massive, cross-bedded sandstone again appears between the Morrison and Lykins formations after being absent from the sections shown on Figures 2 and 6 as far north as Jarr Canyon, a distance of 90 miles. Finlay[11] reports "fine grained friable sandstone at base (of Morrison) overlain by fresh water limestone" in the Colorado Springs area although it was not seen in any of the sections examined by the writer in that vicinity. The log of the well drilled by the Union Oil Company of California a few miles southwest of Pueblo shows 55 feet of white sandstone at this horizon. From Colorado Springs northward to Perry Park, a distance of 35 miles, an overlap of Tertiary beds conceals all older formations and possibly other lenses of Entrada occur there. The distribution of this sandstone agrees very well with the theory of origin set forth by the writer in a previous publication.[12] There seems little doubt that the sandstone at Beulah is Entrada if that at Perry Park and northward is Entrada. Other evidence supporting this view will be pointed out later in this paper.

[10] Ross L. Heaton, "Ancestral Rockies and Mesozoic and Late Paleozoic Stratigraphy of Rocky Mountain Region," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17, No. 2 (February, 1933), p. 162.

[11] G. I. Finlay, "Colorado Springs," *U. S. Geol. Survey Geol. Atlas Folio 203* (1916), p. 7.

[12] Ross L. Heaton, *op. cit.*, p. 128.

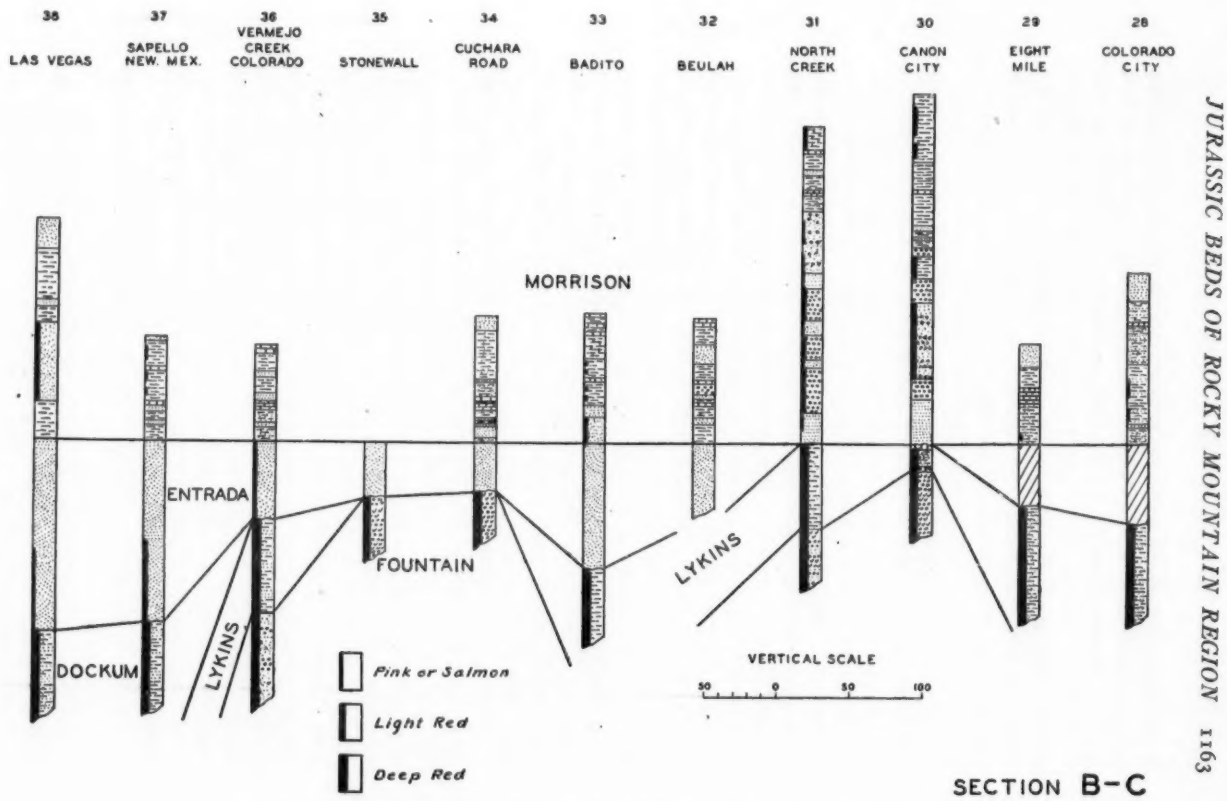

FIG. 6.—Section sheet *B–C* from Colorado City, Colorado, to Las Vegas, New Mexico.

Only 50 feet of Entrada are exposed at Beulah, the base being covered. At Badito the formation is 85 feet thick. It thins to 35 feet in the Cuchara Road and Stonewall sections where it lies on the Fountain formation. The absence of the Lykins indicates an abnormally high erosional area prior to Jurassic deposition. It probably remained higher than the surrounding area of deposition, resulting in a thinning of the Entrada. This sandstone thickens southward to 125 feet at Sapello and Las Vegas in New Mexico.

The relation of the Entrada to the underlying formations is of particular interest in section sheets *A–B* (Fig. 2) and *B–C* (Fig. 6) and adds to the evidence for correlation from the northern to the southern part of Colorado. There is evidence of unconformity between the Entrada and the Jelm (?) in many of the northern Colorado sections. The same is true between the Jelm (?) and the underlying Lykins red beds, which is in agreement with the relationships of the Jelm and Chugwater formations at the type locality of the former.[13] The Chugwater, in its "restricted sense,"[14] includes only beds of Lower Triassic age. Since the thickness of the Lykins of northern Colorado is comparable to the Chugwater and the underlying Permian red beds formerly assigned to that formation, it is a safe assumption that the Lower Triassic is represented in the Lykins in northern Colorado. The contact between it and the Permian has not been recognized, but lies somewhere within a series of soft red beds nearly 1,000 feet thick.

The Lykins thins southward, probably mainly because of a long erosion period prior to late Jurassic time. Thus, at Four Mile Creek, north of Boulder, it is 800 feet thick, but here it includes red beds in its upper part which merge northward laterally into the Jelm (?) sandstone. At this point, and for at least a short distance southward, the Lykins may include Upper Triassic beds as well as Lower Triassic and Permian. The formation thins notably southward and is 600 feet thick at Golden, 280 feet thick at Jarr Canyon, and 145 feet at Colorado City. The assumption must be that the Upper Triassic, Lower Triassic, and a part of the Permian have successively been removed by erosion from north to south, or that one or more were never deposited over all of the area. The latter view seems to be substantiated by a study of paleogeography.[15]

In nearly all of the sections from Morrison south to Badito the

[13] S. H. Knight, *op. cit.*, p. 168.

[14] John B. Reeside, Jr., "Triassic-Jurassic 'Red Beds' of the Rocky Mountain Region," *Jour. Geol.*, Vol. 37, No. 1 (1929).

[15] Ross L. Heaton, *op. cit.*, pp. 150–54.

upper 5 to 20 feet of the Lykins is bleached from the normal bright red to dull red, pink, or greenish, indicating that it has been subjected to a long period of weathering before the deposition of the Entrada or Morrison shales or gypsum.

At Canon City, which lies west of the general line of sections and closer to the ancient positive element, only 30 feet of Lykins remain, the topmost member being a limestone which resembles the "crinkled limestone" which occurs in the lower part of the Lykins throughout the area. Sixty feet of Lykins occur at North Creek and 100 feet at Badito, but it is entirely absent in the Cuchara Road and Stonewall sections, the Entrada lying directly on the Fountain. South of Stonewall red beds resembling the Lykins occupy an interval of 60 feet between the Entrada and Fountain. South of the Colorado-New Mexico line the section thickens very notably. The upper part of the red beds, beneath the Entrada, consists of very sandy shales with many massive, dull red sandstones, in definite contrast to the brighter-colored soft shales of the Permian. These upper red beds are evidently to be correlated with the Upper Triassic Dockum beds of eastern New Mexico and attain a thickness of more than 700 feet at Las Vegas.

SECTION SHEET D–E, BADITO TO PANHANDLE OF OKLAHOMA

This section sheet (Fig. 7) begins at Badito (No. 33) on section sheet *B–C* (Fig. 6). Its purpose is to trace the relationships of the Entrada and associated formations to southeastern Colorado and the Oklahoma Panhandle. The Entrada is traceable without much question to the Ballou Ranch section on the highest part of the Purgatoire uplift. The Exter sandstone of the Cimarron Valley, New Mexico, and the Oklahoma Panhandle was placed in the Morrison by Darton,[16] mainly because it is underlain by variegated shales resembling those of the Morrison but which have been shown by Parker[17] to be entirely distinct from the Morrison and probably of Triassic age. These shales and an overlying sandstone were named the Sloan Canyon formation and the Sheep Pen sandstone by Parker, and they, as well as the Dockum red beds, lie unconformably beneath the Exter in separate localities. The Exter plays out a short distance east and exhibits very fine examples of channel filling near its extreme eastern edge.

The lower Morrison, in the "red beds" area of southeastern Colorado, contains alternating beds of shale, thin limestones, and gyp-

[16] N. H. Darton, "Red Beds and Associated Formations in New Mexico," *U. S. Geol. Survey Bull. 794* (1928), p. 306.

[17] Ben H. Parker, "Clastic Plugs and Dikes of the Cimarron Valley Area of Union County, New Mexico," *Jour. Geol.*, Vol. 41, No. 1 (January–February, 1933), pp. 41–42.

sum. These are correlated with the gypsum beds of the northern Front Range shown on section sheets *A–B* and *B–C* (Figs. 2 and 6). Both the gypsum and the Entrada are present here, while in northern Colorado both are never present in the same section. The age relations have been shown to be the same in both localities.

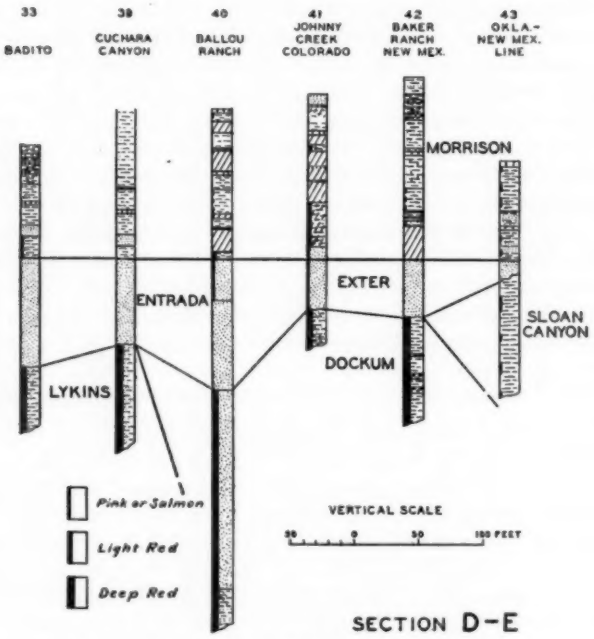

FIG. 7.—Section sheet *D–E* from Badito, Colorado, to Oklahoma-New Mexico line.

The Cuchara Canyon section was measured by A. E. Brainerd and the others of section sheet *D–E* (Fig. 7), except Badito, by Ben H. Parker.

SECTION SHEETS F–G AND H–I, SAN JUAN MOUNTAINS, COLORADO, THROUGH NORTHERN NEW MEXICO

The massive sandstone in northern New Mexico beneath the Morrison and Todilto formations has long been called Wingate[18] and correlated with the type Wingate of the Zuni Plateau. Baker,

[18] N. H. Darton, *op. cit.*

Dane, and Reeside accept this correlation[19] and show the Entrada as extending only a short distance into northwestern New Mexico. They correlate it with the lower La Plata of southwestern Colorado, which is widely distributed and of considerable thickness, a view with which the writer is entirely in accord.

In a former publication[20] some evidence was offered which indicated that the application of the name "Wingate" correctly to the sandstone in northern New Mexico is questionable. The more detailed study, as set forth heretofore in this paper, has strengthened the belief that the so-called Wingate of northeastern New Mexico correlates with the Entrada of the Colorado Front Range. There remained the problem of establishing a reasonable explanation of the relationships of this sandstone with the section of western New Mexico which contains the type Wingate and with the southwestern Colorado section in which the presence of the Entrada is admitted.

Unfortunately the writer had no opportunity to follow out the formations in the same detail as along the Front Range, but he has examined many of the sections in connection with general geological work, both in northwestern New Mexico and southwestern Colorado. Numerous measured sections were available from Darton,[21] and these were used in compiling section sheets *F–G* and *H–I* in portions west of Rowe.

Section sheet *F–G* (Fig. 8) is to be considered from right to left in continuation of the study of the formations from northern Colorado to Las Vegas and then westward to the Arizona-New Mexico line. It is intersected by sheet *B–C* at Las Vegas. From Gallegos, on the Canadian River, west to Rowe, the Entrada thickens gradually and is gray, buff, light red or salmon-colored as in the sections on the north. It lies unconformably on the Dockum red beds of Upper Triassic age. In the Lamy and Sandia Mountains sections it is similar, though somewhat thinner. In the present paper the Entrada is interpreted as being represented in only the upper, light-colored part of the massive sandstone which is called Wingate by Darton in the Laguna (El Rito) and Dripping Springs sections. The lower part is mostly deep red in color and is correlated with the type Wingate. At Grant the Entrada is believed to have played out, leaving the Todilto limestone lying

[19] A. A. Baker, C. H. Dane, and J. B. Reeside, Jr., "Correlation of the Jurassic Formations of Parts of Utah, Arizona, New Mexico and Colorado," *U. S. Geol. Survey Prof. Paper 183* (1936); Pl. 2, p. 16; Pl. 10, p. 32.

[20] Ross L. Heaton, *op. cit.*, pp. 127–29.

[21] N. H. Darton, *op. cit.* Sections 45 to 50, inclusive, in section sheet *F-G* are from the following pages, respectively, of this publication; 139, 130, 117, 120, 94 and 262.

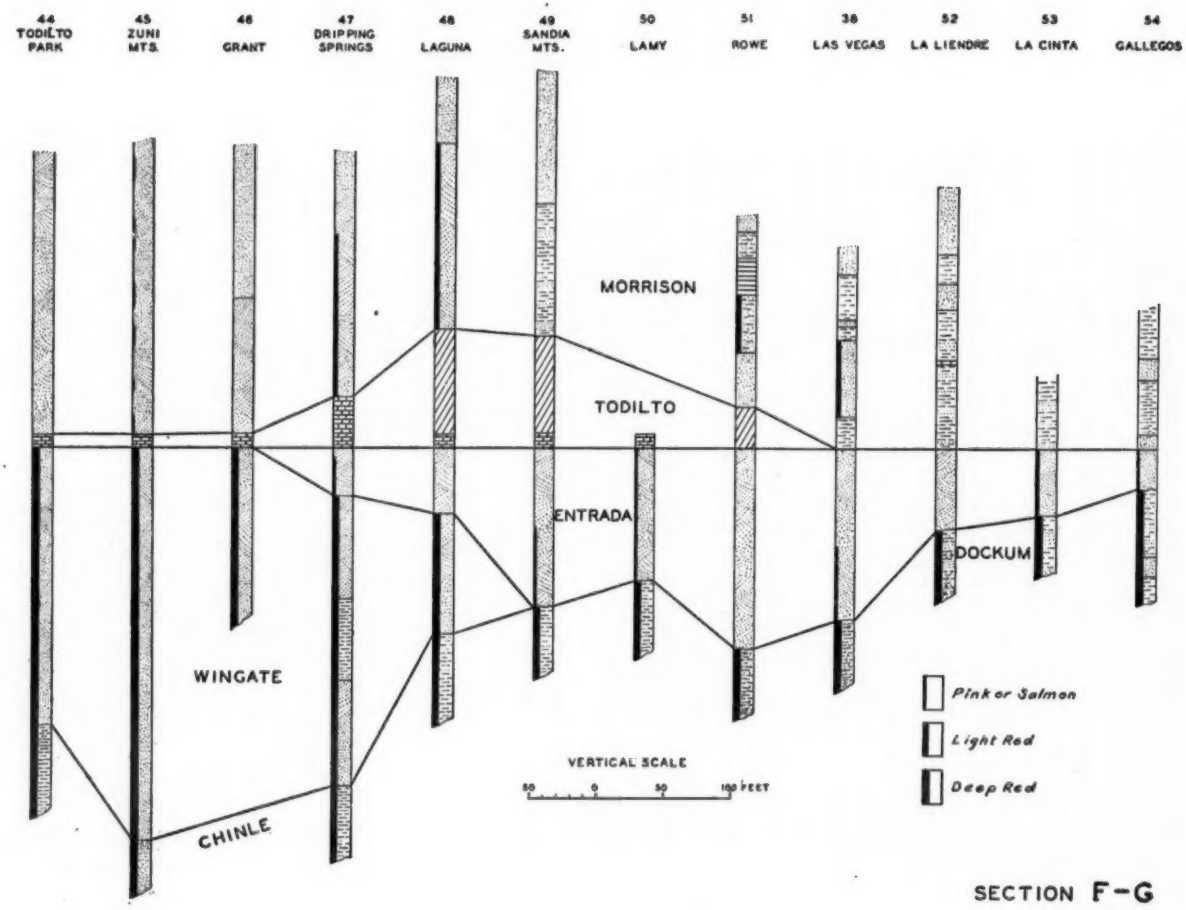

FIG. 8.—Section sheet *F-G* from Todilto Park to Gallegos, New Mexico.

unconformably on the Wingate. This condition persists in the Zuni Mountains and Todilto Park sections.

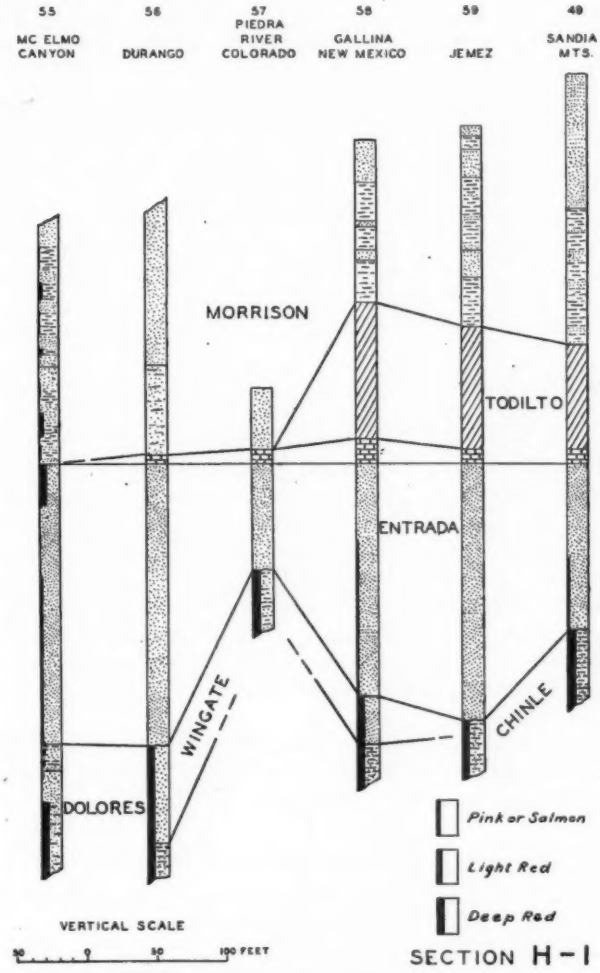

FIG. 9.—Section sheet *H–I* from McElmo Canyon, Colorado, to Sandia Mountains, New Mexico.

Section sheet *H–I* (Fig. 9) intersects sheet *F–G* (Fig. 8) at the Sandia Mountains section, and its purpose is to show the probable

relationships of the Entrada from that locality northwest to the San Juan Mountains and McElmo Canyon, Colorado. The Jemez and Gallina sections were measured by Darton,[22] the Piedra River section by Cross and Larsen,[23] the Durango section by Baker, Dane and Reeside,[24] and the McElmo Canyon section by Coffin.[25] All of these sections were studied by the writer.

The Entrada sandstone retains its color and lithologic characteristics throughout these sections. Its thickness is nearly uniform except at Piedra River where the thinning is doubtless due to its proximity to an ancient positive element. A short distance northeast it overlaps all of the older sedimentary rocks and lies on pre-Cambrian quartzite.

The red sandstone in the upper part of the Dolores formation in the Gallina and Durango sections is believed to represent the Wingate sandstone which grades into the red sandy shales of the other sections. An unconformity below the Entrada is recorded in most of the sections.

The Morrison formation contains the characteristic varicolored shales with lenticular limestones and sandstones from Gallegos to Rowe in section sheet *F–G* (Fig. 8). Westward from that point a persistent limestone is present at the base of the Morrison. It is overlain by thick beds of gypsum from Rowe to Laguna and from the Sandia Mountains to Gallina in section sheet *H–I* (Fig. 9). These together comprise the Todilto formation of Gregory.[26] These beds are thought to be the equivalent of the gypsum of the Front Range and the Purgatoire uplift and to have had a similar origin. West of Lamy the lower Morrison contains great thicknesses of sandstone, probably mostly of eolian origin which have variously been called the Zuni[27] and the Navajo, the latter erroneously, according to Baker, Dane, and Reeside.[28]

No claim is made that the foregoing interpretation of the Entrada-Wingate relationships in western New Mexico has been absolutely proved but there is considerable evidence pointing to the conclusions reached.

[22] N. H. Darton, *op. cit.*, p. 157.

[23] Whitman Cross and E. S. Larsen, "Contributions to the Stratigraphy of Southwestern Colorado," *U. S. Geol. Survey Prof. Paper 90* (1913), p. 47.

[24] Baker, Dane, and Reeside, *op. cit.*, Pl. 3, p. 20.

[25] R. C. Coffin, "Radium, Uranium, and Vanadium Deposits of Southwestern Colorado," *Colorado Geol. Survey Bull. 16* (1920), pp. 55, 70, and 87.

[26] H. E. Gregory, "Geology of the Navajo Country," *U. S. Geol. Survey Prof. Paper 93* (1917), p. 55.

[27] C. E. Dutton, "Mount Taylor and Zuni Plateau," *U. S. Geol. Survey 6th Ann. Rept.* (1885), pp. 135–38.

[28] Baker, Dane, and Reeside, *op. cit.*, p. 5.

The Entrada is lithologically unlike the Wingate both as to color and manner of weathering. The Entrada, in this general area, weathers to rounded forms, is practically jointless, and is banded in gray, pink, and salmon colors. The Wingate is marked by columnar jointing, tends to form vertical, blocky cliffs, and is deep red in color. The Wingate apparently loses its identity in passing eastward and northward and grades laterally into the red beds or, more rarely, has been eroded away.

The questionable relationships of the Wingate at its eastern margin, are mentioned, in several instances, by Baker, Dane, and Reeside.[29] In their Figure 3, which corresponds closely with section sheet *H–I* of this paper, the writer would eliminate the Wingate from the Rio Salado and Chama Basin sections and call the massive sandstone Entrada as in the Piedra River sections. In their Plate 3 the Wingate of the Durango section is believed to be correctly named and is undoubtedly the upper massive sandstone of the Dolores formation of Cross[30] and grades into the red beds of the upper Dolores on Piedra River. In their Plate 4, Baker, Dane, and Reeside show a similar gradation from Gypsum Valley eastward. In their Figure 4 the Wingate of the Bostwick Park section is described (p. 24) as "a salmon colored to yellow, massive fine grained sandstone" and it thereby has a closer resemblance to the Entrada than to the "buff or red-brown" Wingate of the Unaweep Canyon section.

The tendency of the Wingate to become shaly, indicating a gradation into red, sandy shales, is shown by the Dripping Springs section of sheet *F–G* (Fig. 8) of this paper. This characteristic was given prominent mention by Baker, Dane, and Reeside[31] with the statement that

> the Wingate sandstone is persistently reddish and towards the margins of its area of distribution is more and more divided into beds separated by soft, silty sandstone and shale beds. . . . :

and further

> . . . in the marginal areas the Wingate is suggestive of certain Chinle sandstones. . . .

The Entrada, in passing eastward, persists as a clean sandstone until it plays out in practically a knife-edge in the Oklahoma Panhandle.

The assumption that the Wingate merges laterally into the red beds underlying the Entrada, strengthens the possibility that the

[29] Baker, Dane, and Reeside, *op. cit.*, Figs. 2, 3, 6; Pls. 2, 3, 4.

[30] Whitman Cross, "Ouray," *U. S. Geol. Survey Geol. Atlas Folio 153;* "Rico," *Folio 130;* "Engineer Mountain," *Folio 57.*

[31] Baker, Dane, and Reeside, *op. cit.*, pp. 56–57.

Wingate is of Upper Triassic age. One can not avoid a comparison with the merging of the Jelm (?) southward into the red beds of the upper Lykins formation along the northern Front Range of Colorado.

SECTION SHEET J–K, SOUTHEASTERN IDAHO TO NORTHWESTERN COLORADO

Correlations as shown in the eastern part of section sheet *J–K* (Fig. 10) have been mentioned by Baker, Dane, and Reeside.[32] This section sheet serves to corroborate their conclusions by establishing more definitely the equivalencies of formations northwestward into southeastern Idaho. Correlations in the younger members of the sections were determined by Davies[33] some years ago and the upper parts of the sections at Duchesne River, White Rocks, Ashley Valley, Brush Creek, and Tan Cliff were taken from his measurements. The Nugget was measured by the writer. The southeastern Idaho section was taken from measurements by Mansfield.[34] The Spring Creek section in Colorado was measured by Aurand.[35] The sections at Newcastle and Basalt Mountain were measured by Baldwin.[36] All others were measured by the writer.

The Nugget and Twin Creek formations were followed from their type localities in southwestern Wyoming into southeastern Idaho. They were examined at Rock Creek, Wyoming, and at Raymond, Home, and Indian canyons in Idaho. The lithology and thicknesses were nearly uniform and there seemed to be no question as to the correlations. Section sheet *J–K* was therefore begun in southeastern Idaho.

The Nugget is a light buff, cross-bedded sandstone in Idaho, generally very hard and resistant to weathering in contrast to the softer, more massive characteristics of the area on the south and east (Fig. 11). This is probably due to the regional metamorphism to which it has been subjected in that highly folded and faulted region. The Nugget is 1,700 feet thick in southeastern Idaho and thins gradually toward the south and east. It was examined at Park City and Heber, Utah, and, at the latter locality, occurs in the typical massive erosion forms so common in nearly all of the area of its distribution (Fig. 12). The Nugget is correlated with the Navajo sand-

[32] Baker, Dane, and Reeside, *op. cit.*, pp. 14 and 27.

[33] H. F. Davies, unpublished data.

[34] G. R. Mansfield, "Geography, Geology and Mineral Resources of Part of Southeastern Idaho," *U. S. Geol. Survey Prof. Paper 152* (1927), pp. 90, 98, 99, and 101.

[35] Harry A. Aurand, unpublished notes.

[36] Harry L. Baldwin, Jr., unpublished notes.

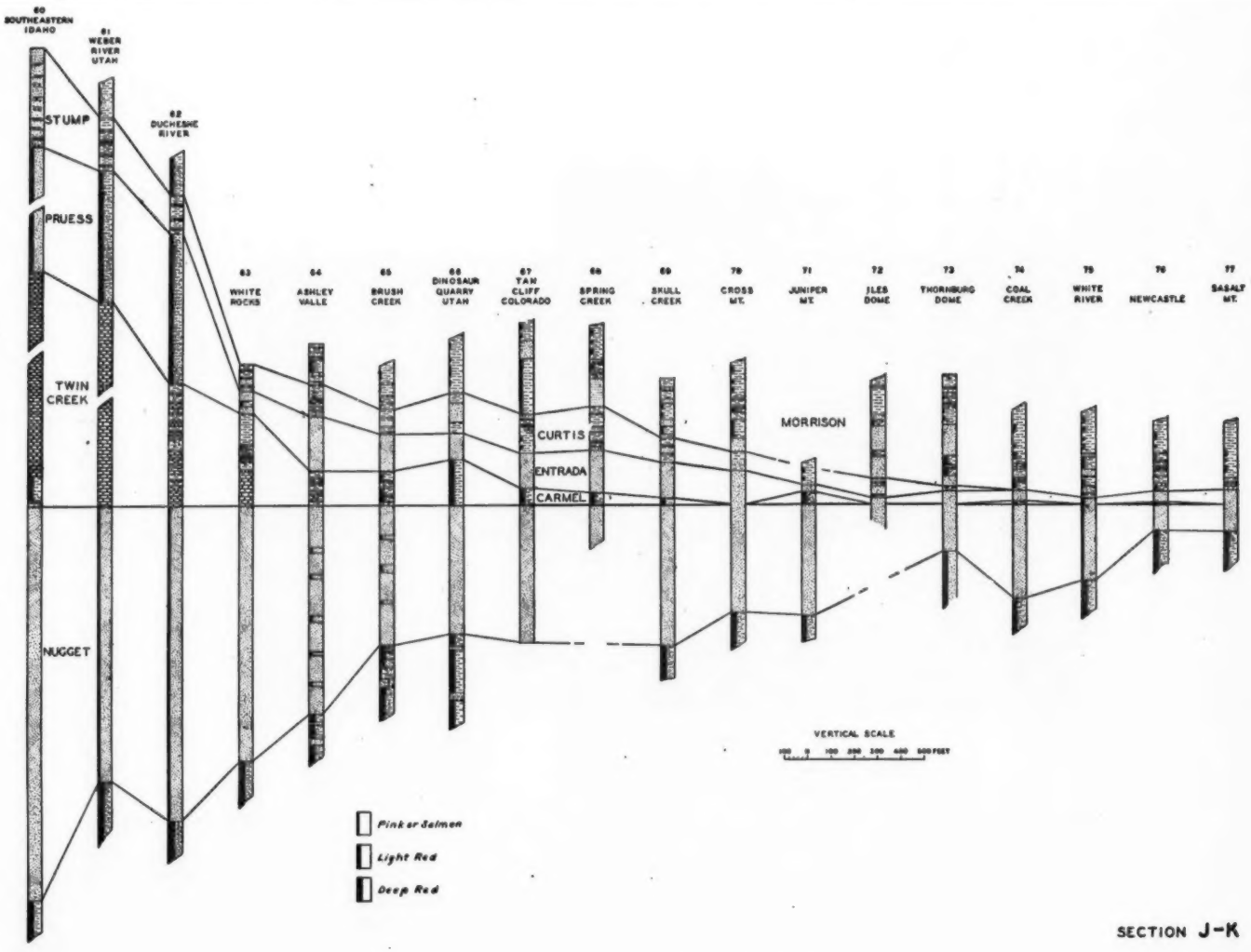

FIG. 10.—Section sheet *J–K* from southeastern Idaho to Basalt Mountain, Colorado.

stone of central Utah and Arizona on account of the equivalency of the marine formations, Twin Creek and Carmel, which overlie them.[37]

FIG. 11.—Typical outcrop of hard Nugget sandstone in southeastern Idaho. Note cross-bedding.

The Twin Creek formation is 3,500 feet thick in the Idaho section and 1,460 feet thick on the Weber River in Utah. It consists almost entirely of limestone at these localities but becomes notably shaly on

[37] A. A. Baker, C. H. Dane, and J. B. Reeside, Jr., *op. cit.*, p. 44.

Duchesne River and has thinned to 500 feet. The thinning continues eastward and red shales appear in the section. The percentage of red shales increases until, in the vicinity of the Colorado-Utah line, the formation, which is here 60 feet thick, is almost entirely red beds. The term "Carmel" is applied to these beds in the eastern Uinta Mountains since it is the equivalent of that formation in the San Rafael region farther south.

The Pruess sandstone of the Idaho section consists of 1,300 feet of dull red to dark red, earthy sandstone, with many partings of red

FIG. 12.—Upper Nugget near Heber, Utah.

shale. The same characteristics prevail, though the thickness decreases, in the Weber River and Duchesne River sections. Between Duchesne River and White Rocks the section changes suddenly into a massive, light-colored sandstone only 100 feet thick with a shale member near the middle. From that point eastward it persists as a light-colored sandstone with typical eolian cross-bedding. Its position beneath a series of shales, limestones, and sandstones carrying Curtis fossils, establishes it as the Entrada sandstone. The gradation of the Pruess into the Entrada, as established by Davies,[38] corresponds very closely with the similar gradation from the red, silty facies to the clean sand facies of the Entrada in central Utah.[39]

The Stump formation is a calcareous sandstone overlying the Pruess in southeastern Idaho. According to Davies,[40] the fossils in

[38] H. F. Davies, personal communication.

[39] A. A. Baker, C. H. Dane, and J. B. Reeside, Jr., *op. cit.*, p. 55.

[40] H. F. Davies, personal communication.

	WYO.	SW. WYO.	SE. IDAHO	SAN RAFAEL UTAH	N. UTAH	NW. COLO.		SW. COLO.	NW. N. MEX.	N. and NE. N. MEX.	SE. COLO.	COLO. FRONT RANGE
UPPER JURASSIC	MORRISON		MORRISON	MORRISON SUMMERVILLE	MORRISON	MORRISON		FORMERLY Mc ELMO	MORRISON	MORRISON	MORRISON	MORRISON
	SUNDANCE	BECKWITH	STUMP	CURTIS	CURTIS (so-called Twin Creek)	SUNDANCE			TODILTO	TODILTO	TODILTO	TODILTO (in places)
	SUNDANCE SANDSTONE		PRUESS	ENTRADA	ENTRADA	so-called Nugget	ENTRADA	LOWER LA PLATA	ENTRADA	ENTRADA	EXTER	ENTRADA
EARLY UPPER JURASSIC	CARMEL ?	TWIN CREEK	TWIN CREEK	CARMEL	CARMEL		CARMEL					
MIDDLE (?) JURASSIC	NUGGET ?	NUGGET	NUGGET	NAVAJO	NUGGET		NUGGET	NAVAJO				
MIDDLE (?) JURASSIC OR UPPER TRIASSIC				KAYENTA				UPPER RED SHALE OF DOLORES				
				WINGATE				UPPER MASSIVE SANDSTONE OF DOLORES	WINGATE	RED BEDS		
UPPER TRIASSIC	JELM	ANKAREH	WOOD	CHINLE	ANKAREH	DOLORES		DOLORES	CHINLE	DOCKUM		JELM (?)

FIG. 13.—Chart showing correlation of Jurassic formations in part of Rocky Mountain region.

the Curtis, as a group, are more similar to those in the Stump than to those in the Twin Creek. This, together with its stratigraphic position, seems to establish the Curtis and Stump as equivalents. The Curtis formation persists eastward well into Colorado and consists of limestone, sandstone, and dark shale. It has been erroneously called "Twin Creek" in many publications but its age has now been definitely established as the same as the Curtis of central Utah and at least approximately the same as the type Sundance of Wyoming.

At the Colorado-Utah line a typical section of the Jurassic rocks below the Morrison consists of the marine Curtis formation, the massive Entrada sandstone, a thin red shale (Carmel), and at the base the massive, light-colored Nugget sandstone, 550 feet thick. Farther eastward in Colorado the Carmel is thin and spotted and is not recognizable in all of the sections. The Entrada and Nugget therefore combine to make one massive sandstone member, the so-called Nugget of the eastern Uinta Mountains and northwestern Colorado. The red member in the upper part of this so-called Nugget is sufficiently persistent to establish a fairly reasonable correlation with the Carmel formation, however. It occurs at other localities not shown on the section sheet, such as at Boar's Tusk and Island Park in Utah,[41] in the K Ranch, Vermilion Creek, and Spring Creek sections in Moffat County, Colorado, and at Rangely Dome in Rio Blanco County. It is not known how far east the true Nugget extends but probably only the Entrada is present in eastern Routt County.

The Curtis or Sundance marine beds wedge out very definitely between Thornburg Dome and the Coal Creek section.

The specific age of the Jurassic formations, as given in the correlation chart (Fig. 13), has been fully discussed by Baker, Dane, and Reeside.[42]

[41] John B. Reeside, Jr., "Notes on the Geology of Green River Valley between Green River, Wyoming, and Green River, Utah," *U. S. Geol. Survey Prof. Paper 132* (1923), pp. 38 and 43.

[42] Baker, Dane, and Reeside, *op. cit.*, pp. 55–63.

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ENVIRONMENTS OF ORIGIN OF BLACK SHALES[1]

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ABSTRACT

Explanations of origin are reviewed and environments in which black muds are in process of deposition are considered. The causes of blackness are examined and attention is given to diagenetic processes that take place in black muds.

It is concluded that colors of black muds are due to several components, of which some are developed in diagenesis and others are due to inclusion of organic matter of various kinds. Sediments that are black at the time of deposition may have the constituents to which blackness is due eliminated during diagenesis, or following lithification. These produce rocks that are not black. It is concluded that black muds develop under several environmental conditions, of which some are found in land waters, some in shallow marine waters, and probably some in deep marine waters, and that retention of blackness is dependent upon the extent of micro-organic processes in the muds.

INTRODUCTION

Scattered throughout the geologic column from the pre-Cambrian are deposits which are, or once were, black shales. These shales are important to the petroleum industry as it is likely that considerable petroleum was derived from them, and they will be more important in the future as they may be expected to become the major source from which the United States will acquire its petroleum before many years have elapsed. The blackness is largely due to organic matter. This in some black shales and slates is recognizable as composed of plant fibers and originally was cellulose or lignin. In other black shales the organic matter is very finely divided and at the times of deposition was evidently largely of colloidal dimensions. Some organic matter originally of this character may be found in all black shales. Still other black shales contain an abundance of spores, spore cases, and pollen grains, and some are filled with remains of fatty algae and these materials were originally high in fats, waxes, gums, and resins. Thus, at the time of entombment the original organic matter of the black shales consisted of visible structures, mostly of plant origin; finely divided materials, probably also mostly of plant origin; and substances consisting largely of those parts of plants with a high content of fats, waxes, gums, and (or) resins.

The black shales composed of a dominance of visible plant materials which originally were cellulosic or ligneous, following David White, are designated humic. Those with a dominance of fatty, waxy, gummy, and resinous constituents are termed bituminous. Between

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these two varieties of black shales there are all gradations. The humic black shales are best exemplified by those associated with, and frequently found in, coal. These are little more than impure, or bone coal. Most bituminous black shales contain marine fossils and are represented in the geologic column by the Makasti shale of the Ordovician of the St. Lawrence embayment, the Utica shale of New York and Ontario, the Chattanooga shale around the Cincinnati arch, and the New Albany shale of southern Indiana. Organic constituents similar to those of the bituminous black shales are present in cannel coals.

The humic black shales contain the organic matter mostly in the form of carbonized or coaly materials and there is a low content of hydrocarbons. The bituminous black shales, on the other hand, contain much organic matter that is not carbonized or coalified, but is in the form of hydrocarbons, or substances from which hydrocarbons may be distilled. The organic matter of the humic black shales is largely of higher plant origin and the plants grew on land or in swamps. The nature of the plant matter is more or less readily determinable. The organic matter of the bituminous black shales is more or less considerably composed of fatty algae, spores, spore cases, pollen grains, wound resin, and similar materials. There may be some land and higher aquatic plant structures, but the conditions either were such as to prevent entrance into the deposits of large structures of land and the higher aquatic plants, or to eliminate these parts of such plants as did gain entrance, thus concentrating the bituminous constituents. The organic matter of the humic black shales seems to be largely autochthonic, or of very short transportation; that of the bituminous black shales may in part be autochthonic, but most seems to be allochthonic. The humic black shales seem to have accumulated in waters of poor circulation in which bacterial or biochemical decomposition was very limited. The bituminous black shales accumulated, in general, in less stagnant and more open waters, but waters that did not have good circulation.

Many black shales contain films, nodules, and crystals of marcasite and pyrite, and in some cases fossils are entirely replaced by these minerals. These sulphides are common in bituminous black shales, they are less common in the humic black shales.

Fossils are generally present in black shales and they are commonly abundant in bituminous black shales. Animal fossils are ordinarily not plentiful in humic black shales but plant fossils are commonly present in excellent preservation. The animal fossils in humic black shales are commonly of land or fresh-water origin, those

in bituminous black shales are aquatic, and many are of marine origin. The marine fossils in bituminous black shales are ordinarily small and most of them belong to the plankton. Fossils of nekton may be present and locally common. Fossils of benthos are rare and most of those present are small forms of which some are the young of larger forms of other sediments. The associations are not ecologic and in no sense are they balanced associations. There is a more or less irregular distribution of fossils in vertical section and they tend to be crowded on certain levels and to be rare or even wanting on others.

Many black shales yield oil on distillation. This is not common, however, with humic black shales, but is general for those of bituminous character.

Strata associated with humic black shales are mostly of continental origin and consist of non-black shales, sandstones, coals, and limestones. Some strata may be of marine origin. The environmental conditions seem to be not greatly unlike those leading to the accumulation of the vegetable matter that resulted in coal. Some bituminous black shales are associated with the same varieties of sediments. The bituminous black shales that contain marine fossils are generally associated with marine shales and limestones and also sandstones. They are commonly antecedent or sequential to marine strata.

It is obvious that the environmental conditions during deposition of the black shales did not permit complete decomposition of organic matter. In both forms of black shales the conditions of preservation were in many places so excellent that many delicate parts of plants and animals were exquisitely preserved. The problems of origin of the black shales evidently thus center around, and require, environmental conditions that permit deposition of organic matter and its preservation to the time of lithification. These environmental conditions are fundamental.

It is obvious that before lithification the black shales were black muds. Muds become black from the presence of organic matter, the black monosulphide of iron which has been designated hydrotroilite, and the black oxides of manganese. Muds that are black at the time of lithification because of the presence of organic matter, or the black manganese oxides, persist in blackness after lithification. Blackness due to manganese oxides is limited in occurrence and may be disregarded as an important factor in black shale coloring. Muds that are black because of the presence of the black ferrous sulphide become light-colored on lithification, as this sulphide changes into either marcasite or pyrite. This cause of blackness in black muds is not a

cause of blackness in black shales. The black shales are thus largely the lithified equivalents of black muds that are black because of contained organic matter.

As many black shales contain authigenic pyrite and marcasite it is evident that the conditions favorable for accumulation of black muds rich in organic matter may also be favorable for the formation of the black monosulphide of iron that ultimately becomes marcasite or pyrite. The environmental conditions that permit formation of black shales from both causes are known to be due to poor circulation and ventilation of water, limited entrance of oxygen connected with the limitation of circulation, and accumulation of toxic products. Absence of oxygen and presence of toxic products eliminate scavengers and the bacteria responsible for decomposition, but favor the presence of the sulphate-reducing bacteria responsible for ferrous sulphide.

THEORIES OF ORIGIN OF BLACK SHALES

There are almost as many theories of the environments of origin of black shales as there are geologists who have studied them. The Genessee black shales of the Devonian of New York were postulated by Clarke (1)[3] to have been deposited in a deep-water environment like that over the bottom of the Black Sea of which the sediments below the depth of about 100 fathoms consist of sticky black muds containing ferrous sulphide and remains of planktonic organisms. The water below the depth of 100 fathoms has no circulation or limited circulation and there is essentially no benthos. Hard (5), on the other hand, referred the Devonian black shales of New York to deposition in shallow water under toxic and saline conditions. The Jurassic black shales of Bavaria and the black shales of the Permian Kupferschiefer have been referred to deposition on deep bottoms (7). Schuchert (14) referred black shales of wide distribution to deposition in more or less closed arms of the sea, and those of small areal distribution to fillings of holes in the sea bottom. He also suggested bottoms beneath sargasso seas. Ruedemann (1911) first considered that the muds which formed the black graptolitic shales were deposited on bottoms between the agitated waters adjacent to the shores and the currentless bottoms of the deep sea. He stated that tranquility of water was essential to deposition of the original black muds. Ulrich (22) stated emphatically that "inclosed and stagnant conditions are not essential to black shale formation," basing this conclusion on his conception of the impossibility of graptolites being carried to heads

[3] Figures in parenthesis refer to references at end of paper.

of narrow bays. He states that the deposits were made in narrow bodies of water that opened into larger bodies at both ends. He also considered the "not infrequent occurrence of intraformational conglomerates in these graptolitic shales as almost conclusive proof that the channels were not of unusual depth." It may be noted that the concept of "narrow bodies of water open at both ends" has little in its support, that the linear distribution of the black shales does not require narrow channels as places of deposition, and that there is little difficulty in transporting planktonic organisms into partially enclosed bays. The statement of the unnecessary presence of "inclosed and stagnant conditions" totally disregards the fact that if circulation had been generally present there would have been total disappearance of all decomposable organic matter unless the rate of accumulation had been so extremely great that it could not be decomposed, and, had such been the case, the plant matter would have been extremely well preserved. Ulrich also suggested that the waters of deposition may have been cold. Only a coldness that eliminates life from a bottom would prevent the presence of a balanced fauna with its attendant scavengers. Such coldness would permit preservation of organic matter, but if there was no life, there would have been little or no organic matter. Polar waters have abundant animal assemblages and organic matter is eliminated on all aerated bottoms. Coldness merely retards, it does not prevent, decomposition of organic matter. Ulrich also suggested possible deposition in "broad shallow pans."

Marr (6) assigned deposition of the Stockdale graptolite shales (Silurian) of Great Britain and Scandinavia in deep embayments open to the west. The southern embayment as drawn by Marr has a somewhat restricted entrance, but in spite of the restriction it is about 100 miles wide at the entrance. The northern embayment narrows inward from the entrance. The depths at the entrances do not seem to have been considered. Deposition was assumed to have been made in waters deeper than 100 fathoms and to account for the absence of benthonic animals bottom conditions somewhat similar to those over the bottom of the Black Sea were assumed. The planktonic and other organic matter responsible for the color were assumed to have been carried into the embayments by storm and other currents. This would not have been difficult considering the widths of the entrances.

Grabau and O'Connell (4) were unable to convince themselves that the Silurian black graptolitic shales of Scandinavia and Great Britain were deposited under the deep-water conditions described by Marr. The fact that the black shales of Scandinavia rest on an eroded surface was thought to preclude deposition in deep water. The black

shales of southern Scotland and northern England were assumed by these students to represent mud deposits made on flood plains and in lagoons of a large delta, or series of deltas, over and into which "periodic high tides washed the planktonic graptolites and stranded them upon the flats." Grabau referred the black shales of the Kupferschiefer to deposition under lagoonal conditions. In his latest approach to the black shale problem Grabau (3) postulated deposition of the muds that formed the black shales in lagoons, over mud flats, and on low lands adjacent to the sea. He placed the black shales in two classes: one, termed normal, is more or less widespread and consists of thin layers of black shale between thicker shales and shaly sandstones of other colors. These form the pure graptolitic shales of Ruedemann (10, 11, 12) and contain an association largely composed of graptolites. They are represented in the geologic column by the Normanskill and Deepkill shales. The shales and shaly sandstones of other colors contain few marine fossils, but graptolites may be abundant in the layers of black shale. The non-black layers are largely referred to fluvial deposition over flood and delta plains; the black layers to inundations by marine waters, the inundations being episodic and not of long duration. The other kind of graptolitic shale is termed the black-shale type; it is the mixed graptolitic shale of Ruedemann. This shale is generally black throughout the vertical section and those of the early Paleozoic contain graptolites and also other fossils of marine origin of which some are benthos. These shales were considered to have been deposited in estuaries, or on mud flats bordering alluvial plains, all connected with the sea.

Richter's (8) studies of the Devonian black Hunsruckschiefer led to the conclusion that the ripple marks, cross-lamination, sandstone lenses, drifted positions of starfish arms and crinoids, and occasional benthonic forms do not indicate that circulation during the deposition of the shales was poor. It may be remarked that occasional starfish, crinoid, and other benthonic remains, ripple marks, and cross-lamination prove nothing except for the particular strata containing these features and these may represent incidents only in the depositional history.

Ruedemann (11,12) in his latest publications accepted Marr's concept of deep-water origin of the black shales and stated that the organic assemblages with the graptolites in the black shales are like those living in existing sargasso seas, so far as life habits are concerned, and he postulated that the animals found as fossils were brought into the embayments attached, generally, to sea weeds which in turn were derived from the plant accumulations floating in sargasso seas.

Scupin (13) referred the black graptolitic shales of southern Sweden that were studied by him to deposition during flooding of low coastal lands by marine waters. The flooded areas are assumed to have lain inland from a shore dune area composed of *Obolus* sands and in the depressions thus flooded sapropelic muds (Faulschlammablagerung) accumulated.

Woolnough (23) postulated that deposition of the black muds that became the black shales took place in inland basins lying on peneplaned lands, and separated from the sea by barriers. Climatic conditions were favorable that permitted balance of inflow of fresh waters from the lands by evaporation so that there was little or no outflow from the basins to the sea, or else loss due to evaporation exceeded inflow from the lands, thus producing inflow to the basins from the sea. Under either condition there was concentration of the salts in solution and greater or less limitation of circulation. Flooding of these "barred basins" during storms, or perhaps during high tides, introduced plankton. As the waters were different from those of the sea, the introduced forms were killed on, or shortly after, entrance. Other plankton and also some nektonic organisms were regularly brought in through passages in the bars. Absence of circulation precluded the presence of a benthonic assemblage with attendant scavengers and thus there was little possibility of delicate organic structures being destroyed. Inflow into the basins to some degree much of the time accounted for the occasional occurrence of plankton in most of the beds and the large numbers introduced in occasional storms accounted for the great abundance in some layers.

The views advanced by Woolnough were partly anticipated by Schuchert (14), Twenhofel (2) and rather fully by Strøm (16), with the differences that Strøm's examples have submerged instead of exposed barriers. Strøm's studies on the coasts of Norway showed that marginal or land-locked basins with shallow thresholds have poorly ventilated bottom waters and that black muds containing much organic matter and filled with hydrogen sulphide constitute the bottom sediments.

It seems to the writer that these various interpretations are due, in part at least, to seeing different sides of a "shield," each observer, after having seen one side, tending to assign all black shales to deposition in a single environment, forgetful of the fact that the concurrence of several environmental factors, which may not always be the same, may produce poor ventilation and toxic conditions in bottom waters, thus insuring deposition of the black muds that make black shales.

CHARACTERS OF BLACK SHALES BEARING ON ENVIRONMENT OF ORIGIN

There are certain features of the black shales that stand out prominently. They are commonly, but not invariably, thinly laminated and they may contain many delicate organic structures in excellent preservation. The laminations indicate that deposition was probably slow and the fine-grained character that it was *largely from suspension*. The excellent preservation of delicate fossils proves that a scavenger population was not commonly present. Neither were the sediments inhabited by mud-eating organisms as burrows are rare and generally wanting. The most abundant fossils are those of plankton or epiplankton and many have extremely extensive geographic distribution. The most characteristic fossils of the black shales are generally far more common in these sediments than in other kinds, but they do not have equal distribution in the vertical section. Some layers have them in extraordinary abundance. They are rare in other layers. Evidently they either reproduced rapidly at times in the waters overlying the black mud bottoms, so that many could die from one cause or another, or they were occasionally introduced in large numbers into these waters, and the waters were those of death and not of life. The distribution of the organisms in many black shales indicates that some organisms were being entombed in the deposits all the time, but that large numbers were entombed at times. Benthonic forms are generally rare, but here and there a layer contains small benthonic forms in abundance. Those present are the young of larger forms or forms that are small when mature. They did not live on the black mud bottoms. Some black shales contain the shells of cephalopods. Many black shales, particularly those of bituminous character, contain an abundance of pyrite and marcasite. There are here and there beds of sandstones and sandy shales.

ENVIRONMENTS OF ORIGIN OF BLACK SHALES

If organic matter is deposited on bottoms of good to excellent circulation and those dominated by conditions that permit the existence of a balanced flora and fauna, and if deposition is not such as rapidly to bury living and dead organic matter, all will ultimately be destroyed before burial.

Under normal conditions the organic assemblage at any place consists of herbivores, carnivores, scavengers, commensals, and parasites. Such is a balanced assemblage or association. The organic assemblages in the black shales have little or no community of ecological characteristics and represent decidedly unbalanced associa-

tions. The assemblages record not the normal depositional conditions of organic materials, but those that do not generally obtain. The few beds of sandstone in the sequences indicate the more or less rare occurrence of currents with competency adequate to transport sands. The black shales show that during most of the time of deposition there was little or no circulation in the bottom waters. The incoming of sands was evidently an occasional episode. The beds of sands prove nothing with respect to the conditions of deposition of the shales except that the surrounding physiographic conditions were such as to make the entrance of an occasional strong current possible.

If conditions are favorable, macroscopic scavengers dispose of most of the dead organic matter and decompositional bacteria assist and complete the elimination. If conditions do not permit the presence of macroscopic scavengers, the destruction of the organic matter may be accomplished to a greater or less extent by decompositional bacteria and the organic matter is destroyed in the following order: (1) proteins, (2) starches and sugars, (3) cellulose, (4) lignin, and (5) fats, waxes, gums, and resins. Under conditions of an adequate supply of oxygen, dependent upon circulation and agitation of overlying waters, everything disappears except hard parts, and even these may not be expected long to survive disappearance of soft parts unless they are buried. Limited circulation leads to elimination of the first members of the sequence and transformation of the sediments by reason of the elimination to a more bituminous character. Burial of the sediments does not guarantee preservation of organic matter. Work done on sediments of some Wisconsin lakes with through-flowing currents, shows that black sediments of the bottom that contain a high percentage of organic matter continue decomposition after burial and at the depth of a couple of meters have lost most of the organic matter and at the same time the blackness of color due to the organic matter.

Quiet waters with limited or no circulation and no "overturn" have a deficiency of oxygen. This leads to absence of scavengers and preservation of organic matter. If the waters contain sulphates, or sulphur is present in the organic matter deposited with the sediments, hydrogen sulphide is formed and ultimately sulphuric acid and ferrous sulphide. Inorganic sediments deposited on such bottoms are derived from planktonic and nektonic and other organisms that may dwell in overlying waters, organic materials floated in from shore or outlying waters, and from the atmosphere. Materials contributed by the atmosphere may have a large content of such substances as spores, spore cases, and pollen grains.

The problem then reduces itself to search for the environmental conditions that produce quietness and absence of circulation of water, as these seem to be the most important requirements for deposition and subsequent preservation of the organic materials that give blackness to muds. All aquatic environments with excellent circulation and thus ventilation to the waters may be eliminated from consideration. There are thus excluded lakes with through-flowing streams with movement extending to the bottom, whereby the waters of the bottoms are stirred and oxygen introduced; lakes with "overturn" and with bottom outflow to remove toxic products; bays with through-flowing streams of sufficient magnitude to stir and remove bottom waters; shallow seas with good to excellent circulation; and the bottoms of the deep seas of the present.

"Overturn" of lake waters has been mentioned. This takes place in lakes of which the waters in summer rise to temperatures producing densities less than that existing just before freezing takes place. Lowering of temperature to 4°C. brings the water to the condition of maximum density. This water then sinks to the bottom, taking with it any contained oxygen, and water on the bottom which has lost oxygen and acquired carbon dioxide is forced to the top. Ultimately all the water in a lake acquires the temperature of 4°C. after which further lowering of temperature reduces the density. The overturn takes place in early winter just before freezing of the surface and in late winter just after breaking of the ice.

Small lakes of the temperate zones without strong inflow or outflow may become so toxic that decompositional bacteria almost cease activity except immediately following "overturn." Black muds thus retain blackness. The deposits of these lakes are not unlikely to have a large content of such difficultly destructible plant matter as spores, spore cases, and pollen grains, and contributions of organic matter from upper waters and shores may also be lush. Similar deposition and preservation may also take place locally about the borders of large lakes where shallowness of water and growth of plants impede circulation. Any decomposition that does take place leads to elimination of the less resistant parts of plants and concentration of the more resistant parts. The deposits become more bituminous as a consequence. Lakes of polar and tropical and temperate-tropical regions do not have biennial "overturn" and unless these have through-flowing waters to introduce oxygen and provide ventilation the bottom waters become permanently toxic and organic matter is excellently preserved. Temperature may be an aiding factor in lakes with very cold waters. Black muds are certain to be deposited under these environmental

conditions. The deposits are likely to be humic if ventilation is very poor, and bituminous if it is fair.

The organic-rich muds of lakes of the characters described may range from dominantly humic to dominantly bituminous. The deposits contain few fossils of aquatic bottom-dwelling animals as the bottoms are altogether too soft, and the bottom waters too toxic to support organisms. The deposits tend to have limited areal distribution and they may pass upward into deposits which are distinctly coaly in the case of small lakes and into clastic deposits of shallow waters in the case of lakes of considerable dimensions.

Lakes with salt water are not likely to have the circulation of fresh-water lakes and the presence of salt modifies the overturn. The waters tend to have high salinity and there may be some slight circulation produced by the sinking of waters from the surface as salinity and thus density are increased by evaporation. Deposition of black muds, more or less rich in hydrogen sulphide, is extremely probable and much of the blackness may be due to the monosulphide of iron that is almost certain to form. Organic matter in the sediments insures retention of some degree of blackness. It is possible that some of the Green River shales may have been deposited under these conditions.

Many bituminous black shales show by the contained fossils that they were deposited in, or in close proximity to the sea. Postulated sites of deposition have included deep sea; deep appendages of the ocean like the Black Sea; shallow bottoms adjacent to the shores; lagoons or basins variously connected with open sea water; mud flats about lagoons, deltas, and estuaries; and river flood plains or other low shore lands occasionally inundated by great waves from the sea. Strange as it may seem, certain black shales have been postulated by different students to have been developed in every one of these environments.

Of deep-sea bottoms, sargasso seas have been suggested by Schuchert (14), and Ruedemann (11) gave this environment serious consideration. Much has been written in cheap fiction about the dense masses of sea weeds floating over the sargasso seas, but the observations of Stevenson (15) do not indicate any great degree of denseness. Ruedemann stated that the sargasso sea of the Atlantic has an area equal to about one third that of the United States, or about 990,000 square miles, and that this area is covered with an estimated 20,000,000 tons of sea weeds. This amounts to about 63 pounds per acre, or less than 1/60 ounce per square foot, certainly not an impressive quantity. These weeds are floating and evidently they sink slowly and it

may be expected that large parts of the 63 pounds will be decomposed and destroyed long before the bottom is reached. It is the writer's opinion that there is little possibility of deposition of black organic muds beneath the existing sargasso seas as these bottoms seem to be adequately aerated, to have a balanced benthonic fauna adequate to eliminate organic matter attaining the bottom, and there seems to be too little organic matter floating on the surface to be of much importance, the slow and long passage to the bottom through ventilated waters would effectively decompose organic matter derived from the surface, and thus there could be little or none deposited with the muds even if it escaped the bottom scavengers. The bottoms of these seas far from land could not possibly have coarse sediments associated with the muds as is the case with many black shales.

The Black Sea is a deep appendage of the Mediterranean and the sediments of its deep bottoms are overlain by toxic and non-ventilated waters. The sediments and immediately overlying waters are populated by sulphate-reducing bacteria and the sediments are of blue-gray color. Lithification will remove any blackness due to the ferrous sulphide as it changes to marcasite or pyrite and the degree of color that remains will depend upon the quantity of organic matter. The organic matter probably ranges from humic to bituminous, dependent upon the degree to which bacterial decomposition advanced before deposition and possibly to some extent after deposition.

Marr's (6) postulate that the Stockdale black shales (Silurian) of Scandinavia and Great Britain were deposited below the depth of 100 fathoms in deep embayments of the sea, that the organic matter was derived from sea weeds and associated and attached organisms introduced by waves and currents, and that the waters were toxic and had no circulation or very little, has received considerable acceptance. Ruedemann (11) in his latest contributions to the black shale problems, his views applying to the Lower Paleozoic black shales of New York, followed Marr in assigning deposition in deep embayments of the sea, but derived the plant matter to some extent from sargasso seas because the characters of the organic associates in the black shales are like those of the existing organisms of the Atlantic sargasso sea. This resemblance seems meaningless considering the long time involved between the past and the present. It is also difficult to understand how sea weeds drifted from shores into sargasso seas would drift back to land and then enter embayments and epicontinental seas. It is not disputed that such might take place, but the two trips would be long and it is doubtful if much would be left to be deposited over embayment bottoms. It seems easier to acquire

the sea weeds directly from the shores and shallow bottoms of the embayments. If the embayments postulated by Marr and Ruedemann had open connection with the sea as shown in Marr's diagram—a width of about 100 miles at the narrowest part of the entrance—it seems very improbable that black muds would be deposited. Storms would bank waters at the heads of the embayments and outward currents over the deep bottoms would result and there would thus be ventilation of the bottoms, scavengers on the bottom, and elimination of organic matter. Also, unless the embayments were surrounded by arid lands, there would be streams flowing into embayments as large as those indicated by Marr and these waters would aid in ventilation. Only if a submerged or exposed barrier was present at or near the threshold of an embayment would circulation of the bottom water be impeded or prevented (17) and the movement of water raised above the bottoms. It is thought that few black shales would result from the conditions postulated by Marr and Ruedemann.

Grabau and O'Connell (4), and Grabau (3) referred the black shales studied by Marr to deposition in lagoons and estuaries, and on mud flats and river and delta plains. Fluvial deposition over flood plains and deltas and marine deposition over the same areas during episodic marine floods were considered responsible for the normal graptolite shales. It was assumed by Grabau that marine floods spread black muds filled with graptolites over river and delta plains where ultimately they became covered with fluvial deposits which are assumed to have formed the red, gray, and green, more or less sandy shales and sandstones which constitute important to large parts of the normal graptolite shales. This explanation of this form of black shales does not seem reasonable. Exposure of the marine muds and the contained graptolites would lead to oxidation and destruction of the organic matter. It seems impossible that many graptolites would be preserved under such conditions. Furthermore there does not seem to be a great deal in the characteristics of the red, gray, and green shales and shaly sandstones of the normal black shales that suggests the fluvial environment of deposition. The black shale type is referred to deposition in lagoons and over mud flats and it seems probable that such may have been possible.

The eastern shores of the Baltic Sea have many bays and sounds in which black muds rich in organic matter and hydrogen sulphide are in process of deposition (19). These appendages of the Baltic are known as limans. The bottoms are essentially unfit for other than mud burrowers and few or no macroscopic organisms are present, but large waves from time to time bring into these embayments

planktonic organisms and the shells of small benthos and such organic remains are locally extremely abundant. The organic matter is largely derived from plants growing on the shores and parts of the bottoms and from indigenous and introduced plankton. The region is humid so that flow from the land in the form of small brooks is adequate to care for losses due to evaporation and normally there is little flow into the embayments from the sea, but it is known that occasional storms flood the limans. The coast is screened to some extent by shallow water, tides are small, and the bays and sounds are shallow, most in the depth range to about 25 feet. These factors are responsible for poor circulation. The accumulations of black muds are locally extended over adjacent sea bottom through occasional movement of water outward from bays. These occurrences of black muds prove that deposition of this variety of sediments does take place in small embayments of tideless or nearly tideless seas and there is absolute certainty that lithification of the black muds of the limans of the east Baltic would produce shales very like the black graptolite shales of the geologic column. It can hardly be doubted that muds similar to those of the limans must frequently have been deposited in bays and sounds of past epicontinental tideless or nearly tideless seas.

Walther noted the accumulation of black muds in deep holes in shallow sea bottoms and termed these halistas and Schuchert (14) has considered that black shales of limited areal distribution may have been deposited in such deep holes. Goldman (2) has described deep holes filled with black muds on the bottoms of Chesapeake Bay. Marginal shallowness of water seems essential, otherwise the bottoms would be so deep before the deep holes began that planktonic organic matter would decompose and disappear in passage downward through aerated waters. There seems little doubt that deep holes in shallow bottoms afford favorable places for accumulation of organic muds as these holes would have little ventilation and thus there would be no scavenger population and organic matter would be preserved. The muds would also contain much hydrogen sulphide and thus the resultant black shales would contain much pyrite and marcasite. The deposits would have limited areal distribution.

Marginal lagoons with narrow entrances to the open sea, the barred basins of Woolnough (23), and basins formed over a peneplaned region undergoing submergence afford environmental conditions that make the deposition of black muds probable. Basins would have different dimensions and connections with the open sea, would range from wide to narrow. Separation might have been due to presence of erosional ridges cut by transverse valleys, or to bars thrown up by

wave action, or to diastrophism. A basin receiving a considerable stream and surrounded by a humid region would have circulation, aeration, and perhaps a bottom fauna depending upon the stability of the character of the waters. Storms from time to time, perhaps high tides, if the parent body was not tideless, would bring in planktonic and nektonic organisms. These would be killed on contact with fresh or brackish waters and to a greater or less extent mingled with remains of animals inhabiting the basins. The dead bodies of many might be expected to return to sea when storms subsided. As the surrounding lands were peneplaned there would not be much entrance of clastic sediments, but this would depend very largely on conditions at the shores. If the sea was tideless, there would be less chance of entrance of waters from the sea and, if the bay was screened by shallow waters outward from the barrier, the possibility of entrance of storm waves would be reduced. This would permit a greater prevalence of scavenger action. It is possible, but not extremely probable, that black shales would develop under these conditions.

If the region surrounding a barred basin did not contribute sufficient water to care for loss due to evaporation, inflow from the sea would take place. This would create greater biologic instability of the bottom, a gradually rising concentration, and the continuous entrance and destruction of planktonic and nektonic animals so that the remains of these would be generally present in the deposits. The occasional storm would introduce large numbers of such animals over a short period. These also would not long survive and would soon sink to the shallow bottoms and become immersed in the soft sediments. Absence of circulation over the barrier and the presence of sulphates in solution would lead to formation of hydrogen sulphide, difficult conditions on the bottom, and absence of a scavenger fauna. Black muds would most certainly result.

Few large barred basins of the form postulated by Woolnough are now in existence. There are many small ones. But the rarity of such embayments on the present surface is not a source of difficulty as no peneplaned surfaces are now in process of submergence, but there can be little doubt that peneplaned areas have existed and have been submerged during the times that the graptolites and other organisms of the Paleozoic black shales flourished and there were probably large barred basins during some of the geologic periods.

The idea of land-locked basins is not new and others than Woolnough have pointed out that such basins may receive deposits of black muds. Schuchert in 1910 stated that black shales of wide distribution were deposited in land-locked basins (14) and the present

writer in 1931 suggested that the extensive black shale formations of the geologic column were deposited in land-locked arms of nearly tideless seas under conditions not permitting effective circulation of bottom waters and that the marine planktonic organisms introduced into these waters in storms were killed on entrance. Strøm (17) has shown that on the coast of Norway all embayments with "thresholds," or entrances less shallow than the waters within the embayments, contain deposits of black organic muds in which hydrogen sulphide forms. The waters are brackish to fresh, are surrounded by lands of much relief, and have inflow of fresh water from the land. The embayments are barred except that the bars are not exposed as in the hypothesis of Woolnough. Strøm's paper preceded that of Woolnough by one year and gives many examples of black mud deposition in barred basins (Fig. 1). Similar basins must have existed in the past.

It is believed the deposition of black muds resulting in black shales may take place on an extensive scale in shallow epicontinental seas of which the connections with the open sea are of such character as to render the epicontinental seas more or less nearly tideless. If such an epicontinental sea was surrounded by lands of little relief there would be small introduction of clastics. A sea of this character would have limited circulation because of absence of tides, and waves would not be likely to reach the shores with much power to erode for the two reasons that they would break a long distance out from the shore and the shallow bottoms would be covered with plants so as to damp or kill movement. On the shore margins of an epicontinental sea of this kind there would be fresh-water aquatic plant growth nearest to the shore and salt-water aquatic plant growth seaward. The places of division between the two kinds of plants would be poorly defined and fluctuating from time to time. Fresh waters flowing from the margining lands would maintain the width of a fresh-water belt dependent upon the inflow and the zone of salt-water plants would have width determined by ease of circulation through the plants, the quantity of fresh water brought into the sea from season to season, and by the width of the shallow-water bottom upon which salt-water plants might grow. The fresh waters adjacent to the shore would form a barrier preventing encroachments to the shore by salt waters. Absence of strong currents due to absence of tides and the plant-covered shallow bottoms leaves diffusion as the chief method of extending salt-water influence. Storms from time to time would overwhelm the fresh-water area with salt water, annihilate any fresh-water animals present and leave numerous remains of plankton, nekton, and small benthos. Heavy rainfall would freshen the salt-water areas. Flow of

fresh water from the land would drive the storm-carried salt water seaward and kill any salt-water animals left behind. The conditions throughout such an environment as this would be those of decided instability and fresh-water animals once annihilated might have difficulty in reëstablishing themselves over the plant-covered bottoms. Poor circulation and bacterial activity would develop toxic waters

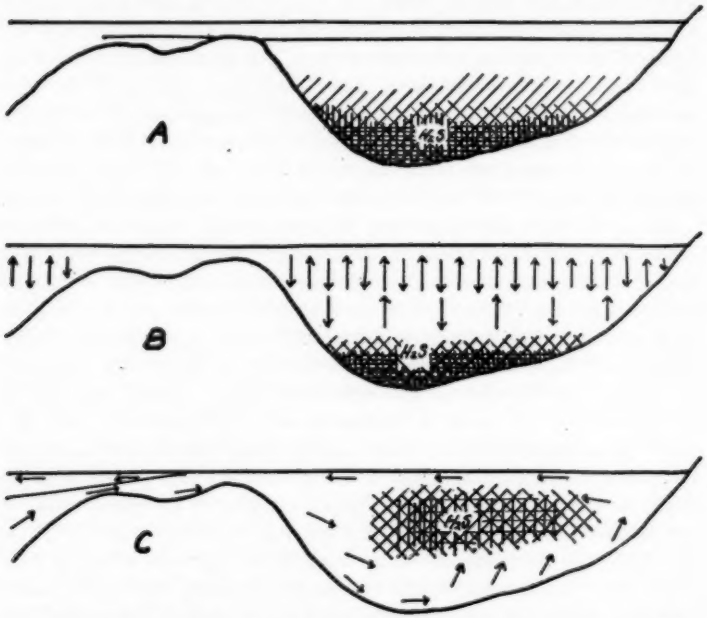

FIG. 1.—Land-locked basins. Reproduced from Strøm. *A* shows a basin with a threshold preventing entrance of deep waters from the sea and thus with poor or no circulation. There is a surface layer of water of low salinity which is therefore light. This seals the deep water from communication with the atmosphere. The bottom waters contain hyd rogen sulphide in quantities indicated by shading. The bottom beneath the hydrogen sulphide is covered with black mud on which there is little or no benthonic life. *B* sho ws the same basin with some refreshing of the water through vertical convection currents. The refreshing does not reach the bottom so that this is still covered with hydrogen-sulphide waters. *C* shows waters in which some circulation is brought about by increase of density of the surface waters, or increase of density of the threshold waters, with some assistance from offshore winds. This causes the hydrogen-sulphide waters to rise with consequent destruction of planktonic and nektonic life. The remains are then to some degree entombed in the bottom sediments. Circulation thus produced may be expected to be episodic and non-periodic.

and sulphate-reducing bacteria would lead to formation of hydrogen sulphide. If sea-level was rising the black mud belt would migrate with the shore, invading the land area and perhaps retreating land-

ward on the seaward side. If sea-level were falling the reverse might be true. Where sea-level was rising, the black muds would be oldest at the places of first deposition and become progressively younger with advance on the land. Where sea-level was falling, the oldest deposits would be on the landward side. If there was rise followed by fall of sea-level, the youngest black muds of the advance would pass into the oldest representing the beginning of the retreat. A wedge of more or less normal marine sediments would lie between the black

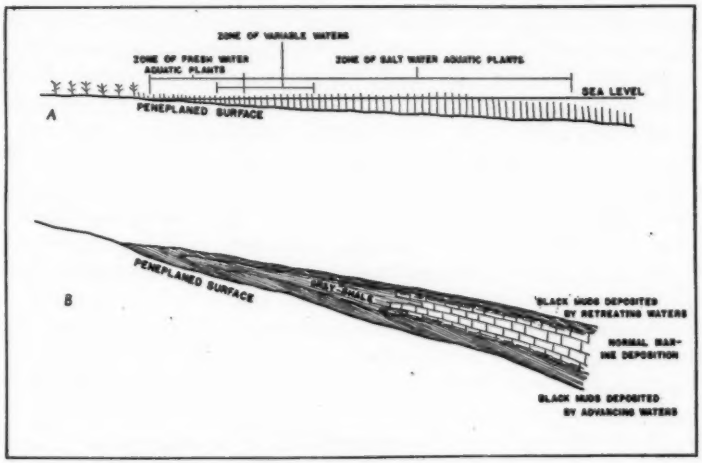

FIG. 2.—An explanation of deposition of black muds in shallow tideless waters. A peneplaned surface, or any level surface of any origin, is gradually submerged with plants adjusted to depths. The marginal areas are covered with aquatic plants bathed by fresh waters. Seaward the aquatic plants are bathed by brackish and salt waters. Between the salt-water and fresh-water plants is a zone of variable waters. It is postulated that the plants would hinder and largely prevent circulation, thus insuring deposition of black muds. An advancing sea would leave a deposit of black mud over the area of advance and this would become covered by other deposits as the waters become too deep for the plants to thrive. A receding sea would leave a deposit of black mud over the areas deserted.

muds of the advance and the retreat. Figure 2A represents the conditions postulated for black-mud deposition over weed-covered bottoms of shallow, tideless epicontinental seas, and Figure 2B shows the form of deposit that might result from advance and retreat of a tideless epicontinental sea over a level or nearly level land. Deposits made in the way postulated might cover very extensive areas in case of an advancing sea and they might be very thick. They likewise might cover very extensive areas in case of a receding sea, but would

not be likely to be very thick. They would have linear distribution in case of stationary sea-level.

Under existing climatic conditions the great oceans have a deep circulation that is poleward from the equator in the upper waters and equatorward from the poles in the bottom waters. Ventilation of the bottom waters is thus maintained and the conditions on the bottom are oxidizing to a greater or less extent. Under existing conditions accumulation of black muds does not generally take place as there is adequate oxygen to maintain scavenger organisms and decompositional bacteria to care for elimination of organic matter. Properly placed elevations on the bottom would impede circulation, make ventilation less effective, and prevent entrance of oxygen. Black muds would result. Bottoms of black muds have recently been described over parts of the bottom of the Arabian Sea (15) where some conditions must impede or prevent circulation. Under more equable climatic conditions than now exist there is a strong probability and perhaps a certainty that much of the bottom of the deep ocean would be without oxygen. Under such conditions there would be little elimination of organic matter and black mud deposition would take place on an extensive scale. There need be no connections between such bottoms and sargasso seas, but nothing would preclude a sargasso sea being above such a bottom of restricted ventilation. None of the black shales studied by the writer can be assigned to deposition under such conditions.

SUMMARY

It seems certain that the original black muds that form black shales originate under conditions of poor circulation so that no oxygen or only limited quantities can enter and toxic conditions develop, or under conditions of such rapid accumulation of organic matter as to be beyond the disposing ability of scavenger and decompositional organisms. The latter is rare. The former condition is common, as follows.

1. In lakes and ponds without through-flowing streams and with or without overturn. Conditions are best if there is no overturn. The deposits tend to cover limited areas and are more likely to be humic than bituminous.

2. In deep salt-water appendages of the ocean like the Black Sea. These may be large and the deposits in some places humic but more generally bituminous.

3. In deep holes of shallow-water bodies, either in lakes or in the sea. Most of these are small. Some of the deposits are humic; probably more of them are bituminous.

4. In shallow lagoons, bays, and sounds of tideless or nearly tideless seas. Most of these cover small areas and are generally bituminous.

5. Over mud flats of lagoons, estuaries, and deltas. These are more likely to be humic than bituminous.

6. In barred or nearly land-locked basins separated from the open seas by visible or submarine barriers preventing effective circulation, preferably surrounded by lands of little relief and under climatic conditions not permitting inflow of fresh waters into the basins to exceed the loss due to evaporation so that there must be inflow from the sea. Deposits are likely to be bituminous.

7. Over plant-covered bottoms of tideless or nearly tideless shallow epicontinental seas. Deposits are likely to be bituminous.

8. Under conditions of equable climatic conditions whereby the deep waters of the whole or parts of the sea fail to receive oxygen because of absence of a deep oceanic circulation like that now existing or under existing conditions because barriers, either visible or submarine, locally prevent this deep submarine circulation from the poles to the equator.

9. Black mud deposits do not persist over the present deep ocean bottoms, beneath present sargasso seas, in embayments with open connection with the sea and with graded bottoms to the sea, or in lakes with through-flowing streams.

10. It should be obvious that black muds are deposited under a considerable range of physiographic aqueous conditions, of which each produces absence of circulation of overlying waters and this limits entrance of oxygen. Black shales, correspondingly, should not be assigned to any general condition, but *each black shale formation should receive interpretation on the basis of the characteristics of that black shale formation.*

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LOUISIANA STREAM PATTERNS[1]

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ABSTRACT

Louisiana streams present a considerable variety of patterns. Contrasting types depend upon gradients, alluvial materials, load, variations in stage, and other factors of stream history. They serve as useful tools for the unraveling of flood-plain history, some characteristics, such as meander pattern, having greater reliability than others, such as channel width. In upland parts of the state, boundaries between aggradational surfaces may be distinguished on the basis of stream pattern alone. Studies thus far conducted in the field of stream planimetry suggest that this discipline might well be extended and offers the possibility of conclusions as significant as those derived from the geomorphological study of land forms.

INTRODUCTION

In a rugged region the longitudinal and transverse profile characteristics of stream valleys are so striking, and their tectonic implications are so obvious, it is little wonder that they have become the subjects of extensive geologic investigation and a comprehensive descriptive vocabulary. The streams of a flat region, however, appear monotonous on casual acquaintance. Their gradients offer little to stir the imagination of the geomorphologist. Many are without valleys. Their study requires many departures from the conventional vertical-section treatment of the geologist and the adoption of the less investigated discipline of planimetric consideration.

From the pattern characteristics of low-gradient streams, such as occur in the Coastal Plain of Louisiana, arises the suggestion that the extension of an essentially geographical technique may well deserve as detailed investigation as that dedicated to longitudinal and transverse profiles. The possibility of compiling a map of the United States showing provinces, regions, and areas differentiated on the basis of stream patterns may appear remote, but such a map might well become exceedingly useful to geomorphologists. With such a goal in mind, foundational investigations must focus attention on small areas, in order to explore the depths to which pattern studies should penetrate, as well as the desirability of extending the rather modest vocabulary which has resulted from previous studies in this field.

FUNDAMENTAL PATTERNS

The two fundamental patterns of aggrading streams appear to be meandering and braiding. The former is characterized by channel simplicity, the latter by channel complexity. At most places along

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its course, a meandering stream occupies a single, simple channel. Where towheads, or lens-shaped islands, occur as channel complications, there is rarely a close approach to channel symmetry on their sides. The channel of less width is called a chute. A braided stream normally occupies many channels. Its bed might be described, in many cases, as a maze of chutes entwining a multitude of towheads. At highest stage a braided stream simplifies its channel and temporarily assumes many meandering characteristics. At lowest stage a meandering stream may assume characteristics of braiding.

Available load appears to be the factor separating meandering from braided streams. A smaller load, in proportion to carrying capacity, at the moment, makes for meandering, a larger load, for braiding.

The immediate sedimentary load of an aggrading stream is derived from its own flood plain. We may look toward distant uplands only as ultimate sources of flood-plain materials. Though the alluvial deposit within a valley is originally derived from outside sources, entrained load is not likely to travel any considerable distance before coming to rest. Only the very finest materials, in suspension and solution, disobey this rule, but they are not the most significant constituents of flood plains, nor are they the most important elements in a stream's load.

The burden added to the Mississippi River as the result of bank caving alone, in the course of its alluvial valley below Cairo, has been estimated at about four times the total sedimentary discharge of the entire stream as stated by Humphreys and Abbot.[3]

Much of the load derived from caving banks, channel scour, tributary streams, and other sources ordinarily comes to rest on the next crossing downstream. Crossings are the shoal areas between bends, where the thread of the active current crosses from one bank to the other. Shifting channels require bank attack at many points. They also leave materials deposited on crossings incorporated in the

[3] Based on the work of J. L. Riddell, *De Bow's Review*, 2 (1846), pp. 433–48, Humphreys and Abbot, "Physics and Hydraulics of the Mississippi River," *U. S. Army Engrs. Prof. Paper 4*, Philadelphia (J. B. Lippincott, 1861), reprinted, with additions, as *U. S. Army Corps Topogr. Engrs., Prof. Paper 13*, 691 pp., maps (Washington, 1876), state an average of about one million tons per day as the sedimentary discharge. D. O. Elliott, *The Improvement of the Lower Mississippi River* (Vicksburg, 1932), pp. 41, 125–27, says the total sedimentary discharge is the equivalent of a prism of silt from about 205 to 390 feet high and one mile square. J. A. Ockerson, *Reports of the Mississippi River Commission for 1884 and 1892*, and B. M. Harrod, *ibid., Report for 1885*, estimate the amount of bank caving. Ockerson concluded, in 1892, that annual caving between Cairo, Illinois, and Donaldsonville, Louisiana, is the equivalent of a prism of silt 810 feet high and one mile square. A detailed description of different kinds of bank caving occurs in the *Report of the Board on the Examination of the Mississippi River below St. Louis, Missouri*, House Doc. No. 50, 61st Congress, 1st Session.

deposit of the flood-plain alluvium as a whole. This process assures a thorough mixing of alluvium and is known as trading. The bulk of the sedimentary load at any place along the channel is soon traded for materials from the flood plain itself.

A study of bed-load samples of the Mississippi River and its chief tributaries, by R. Dana Russell,[4] indicates a negligible change in the mineral composition of the load below each tributary. This is proof of the effectiveness of trading. On entering the alluvial valley, each tributary trades its own load, which is distinctive enough, for that of the alluvial valley, and hence is unable to effect any significant change in the nature of the materials being carried in the main channel.

In alluvial valleys as large as those of the Mississippi and Red rivers in Louisiana, processes of flood-plain deposition tend to minimize point-to-point contrasts in the nature of stream load and thereby simplify one of the fundamental factors in regard to stream patterns.

In general, aggrading streams flowing through flood plains composed chiefly of clay and fine silt are not easily overloaded and therefore tend to meander. Those flowing through sandy or gravelly flood plains are more readily overloaded and therefore tend to anastomose, or display the effects of braiding. Meandering streams ordinarily have deeper channels, with relatively steep slopes toward the banks and flat floors in cross section. Braiding streams have flatter and more irregular cross sections. This relationship between channel section, pattern, and bank materials has been discussed by Leighly.[5]

The effect of an increased gradient on a flood-plain stream is typically that of increasing its load. This causes the channel to widen and shoal, leading to a braided pattern. Gentler gradients decrease the load of such streams and lead to meandering patterns. Unconsolidated or incoherent materials of bed and bank increase the load and braiding tendencies. A similar effect is produced by reduction in current velocity when a stream with considerable load discharges into a quiet body of water.

In the relatively fine-grained flood-plain materials of southern Louisiana, meandering is the typical pattern of streams in alluvial valleys. Braiding is typical of crevasse channels leading from natural levee crests to back-swamps. Meandering occurs along the trunk streams. Braiding occurs on some of the tributaries, particularly

[4] Presented before the Geological Society of America at the Washington meeting of 1937.

[5] J. B. Leighly, "Toward a Theory of the Morphologic Significance of Turbulence in the Flow of Water in Streams," *Univ. California Bull. Dept. Geog.*, 5 (1932), pp. 1–22.

those with steep gradients and an entrained load of sand or gravel. Tendencies toward braiding are evidenced along the shores of the Gulf of Mexico and other bodies of relatively still water.

Volume alone appears to have little effect on channel section or stream pattern. Both large and small streams meander in deep channels across silty flood plains and carry about the same types of entrained load. The effects of volume are quantitative, rather than qualitative. Meander belts are wider along streams with greater volumes. Stage difference, between high and low waters, an expression of volumetric change, is important in speeding pattern-forming processes. A channel section and pattern in equilibrium with a low-stage discharge is out of equilibrium with high-stage discharge and readjustments occur as stage alters. If stage differences are large, the required degree of channel readjustment is also large and pattern-forming tendencies are emphasized.

MEANDER PATTERNS

Straight sections along the channel of a meandering stream are called reaches. Curves are called bends. In order to designate the pattern of a stream as meandering, there seems to be little point in requiring any particular frequency of bends, or in demanding any particular limits for their radii of curvature. There may be some advantage in the recognition of degrees of meandering. These might be based upon such criteria as the presence or absence of cut-offs, with their attendant ox-bow lakes, the ratio between mid-channel and air-line distances, or that between mid-channel and the thread of the current. There appears to be little logic in failing to recognize the meandering tendencies of such a comparatively straight stream as the Mississippi River below English Turn[6] by excluding it from the pattern class, meandering.

As far downstream as False River, in Pointe Coupee Parish, Louisiana, the Mississippi River displays a meander pattern in full development, with many cut-offs and ox-bow lakes along its course. Here the difference in stage between highest and lowest waters is in excess of 40 feet and the channel is called upon to adjust itself to tremendous sectional changes between flood and low stages. Near New Orleans, extreme stage differences are less than 25 feet and the channel section in equilibrium with highest water is not greatly different from that at lowest. Meandering tendencies are thus minimized and the pattern is characterized by less arcuate bends. Not far downstream from Orleans Parish, stage differences are but 10 feet, and toward

[6] The last main bend downstream, in the vicinity of New Orleans.

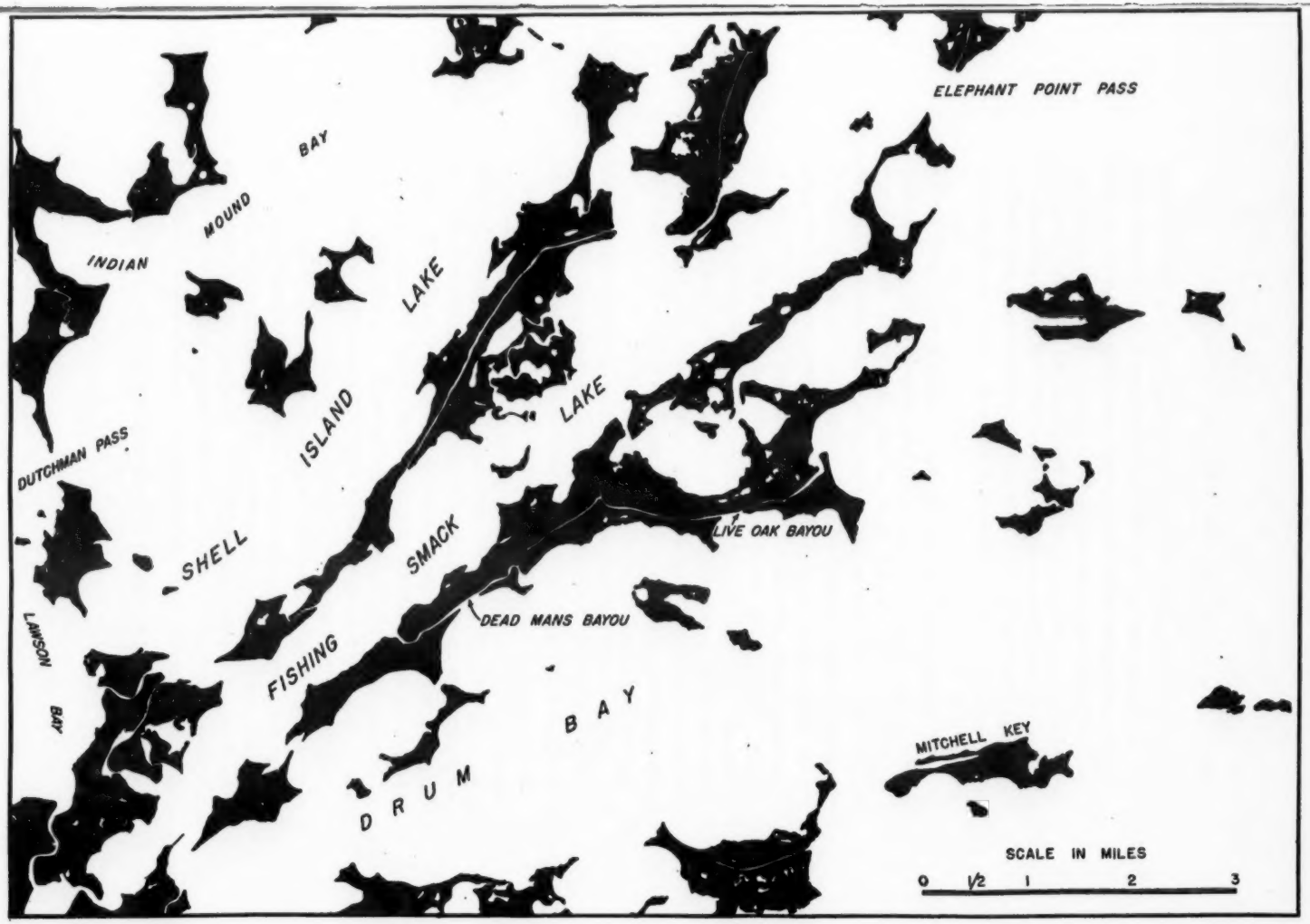

FIG. 1.—Straight distributary channels of St. Bernard sub-delta of Mississippi River. Each distributary channel is flanked by its own pair of natural levees. Submergence of region has lowered them, so that they have become "double islands." Across regional grain of radiating distributaries are meandering tidal channels, a good example appearing near lower left corner of figure. Taken from *U. S. Coast and Geod. Survey Charts T-5322* and *T-5327*.

the Head of Passes they are barely 5. Meandering is a very slow process in a river the size of the Mississippi under such limited stage differences, particularly in a flood plain consisting of fine silt and clay and so the stream course is relatively straight. Even here, however, the channel is really divisible into bends and reaches. A ship coming from the Gulf of Mexico must steer some sixty different courses before reaching New Orleans. The radius of curvature of each bend is typically large, but the bend exists because the river has meandering tendencies.

Whereas a stage difference of 5 or 10 feet is insufficient to develop impressive meanders in a channel as large and young as the Mississippi River below English Turn, it does so in small channels of the lower delta. This fact led to the recognition of "effective stage differences."[7] With a width of from ½ to more than 2 miles and depth of from 100 to nearly 200 feet along most of its channel, a 5-foot range between highest and lowest stages on the Mississippi represents an almost insignificant effective stage difference. In a near-by marsh channel only 5 feet deep at low water, 5 feet is a terrific difference in effective stage. In striving first toward the type of channel demanded for its low-water discharge and later for that demanded at high water, the smaller stream of the lower delta attains a well developed meander pattern in a very few years.

Every straight channel in the lower delta of the Mississippi River is either an active or relict main river channel, important distributary, or pass. Every channel of this type has natural levees which rise above the levels of surrounding marsh and effectively prevent tributary inflow. Each junction along one of these channels is a point where a crevasse or distributary outflow has taken place. Lacking tributaries, such channels deteriorate rapidly when abandoned. The marshes are drained by the meandering channels between the levees of streams associated with the main river system. Natural levees are inconspicuous along these channels and tributary branches are the rule. Many of these low streams conduct tidal waters and meander very actively.

East of New Orleans, along the course of Bayou La Loutre, is the huge St. Bernard sub-delta of the Mississippi River, which, at least in the main, appears to have been the lower delta of the river not more than 1,000 years ago. Part of the distal portion of this sub-delta is shown in Figure 1. The eye is immediately attracted to several islands appearing to radiate from a common center. These are

[7] R. J. Russell, "Physiography of Lower Mississippi River Delta," *Louisiana Dept. Conservation Geol. Bull. 8* (1936), pp. 134–37.

"double islands" formed as the result of submerging the natural levees of old Mississippi distributaries. The channels within the islands are now decadent, and as a result of disuse have shoaled to low-water depths of from 1 to 3 feet. Lacking flow, other than that necessary to fill and empty them as tides rise and fall, such channels retain their original distributary straightness. The original back-swamp areas between levees are now submerged so as to have become bays deeper than the channels themselves.

Decidedly deeper than the abandoned distributary channels of the St. Bernard sub-delta are the meandering tidal channels rnnning across the grain of this territory. A conspicuous example is shown near the lower left corner of Figure 1. Other examples occur near by and short tidal channels enter Dead Mans Bayou, on the island between Fishing Smack Lake and Drum Bay. These tidal channels flow with considerable velocity during and after periods of east wind, when waters collecting in the western end of Mississippi Sound, and the chain of lakes extending west to Lake Maurepas, drain southward into Chandeleur and Breton sounds. The depths of tidal channels in this area range between 4 and 20 feet. Effective stage differences are sufficient to cause them to meander rather actively. Lunar tides are not impressive along the shores of the Gulf of Mexico, but shifts in wind direction are frequent and the direction of flow is reversed many times in the course of a month. Meandering is decidedly more favored in tidal than in non-tidal streams for the reason that rises and falls in water level are more frequent. Reversals in direction of flow tend to produce more symmetrical meanders than those along non-tidal channels. Distributary channels appropriated for tidal use, as in the case of a portion of Dead Mans Bayou, display decidedly more tendency to develop bends than non-tidal distributaries. Meandering of tidal channels has reached the stage of cut-offs and ox-bows in some cases, an example being Kelso Bayou, the stream between Calcasieu and Black lakes, in Cameron Parish, of southwestern Louisiana. Beyond the influences of Mississippi Sound, and particularly along the coast west of the delta, tidal-channel meandering activity is proportionate to the extent of lakes and basins to be filled as waters rise and drained as they lower.

Widths of meander belts have been related to channel widths by Jefferson.[8] The recognition of this principle may be regarded as the most important key to the deciphering of flood-plain history. Jefferson found that meander belts, as measured between lines tangent to outer

[8] Mark S. W. Jefferson, "Limiting Widths of Meander Belts," *Natl. Geogr. Mag.*, Vol. 13 (1902), pp. 373–84.

bends, are ordinarily about 18 times as wide as the channel forming them. He presented statistical support of this rule and pointed out some exceptions, such as the Mississippi River below Baton Rouge. The rule must not be pressed too far. It must not be used for very limited distances along stream courses, as channel widths vary too much from place to place. It will not cover immature meandering, such as occurs along the Mississippi below English Turn. Nor will it cover cases of inhibited meandering, such as arise where streams impinge against valley walls. It will prove most useful in determining whether meander patterns are active or inherited.

Aggradation in Louisiana has been so rapid that no part of any active flood plain of an important stream was contemporaneous with Quaternary glaciation. Deposits which accumulated prior to the latest, Recent, rise of sea-level now stand as terraces in central and northern Louisiana, or lie buried beneath marsh deposits along the coast. No channel scar in the alluvial valley suggests volumetric change on the part of the Mississippi, Red, or other large stream. It is for this reason that we may trace abandoned channels of these rivers on the basis of similarity between meander patterns of active and relict courses.

The meander patterns of the active Red and Mississippi rivers differ in proportion to the relative sizes of their channels. Radii of curvature and width of the meander belt are much smaller along the Red. Traces of abandoned channels display an identical contrast. Figure 2 exhibits the way that old courses may be identified in the alluvial valley of central Louisiana. Red River flows eastward across the area shown in the map. Where it enters this area, the Red flows in a channel of its own creation, and displays its own typical meander pattern. This pattern may be followed upstream, past Alexandria, through Red River Valley, to the northwest corner of the State. Downstream, however, at a point readily apparent in the figure, the pattern changes abruptly for the reason that the Red here adopts one of the many abandoned Mississippi River channels of the alluvial valley. In using this channel, Red River has reversed the original direction of flow. Black River flows down the same Mississippi course, from the north. Bayou Natchitoches uses it farther south. Beyond the junction of Red and Black rivers, Red River again follows a channel of its own creation. Meandering has not yet progressed very far in this channel, chiefly because of its recency, but the bends being formed are those appropriate to the Red.

A relict course of the Mississippi River, older than the Black-Red-Natchitoches channel, is also preserved in the flood plain shown in

Figure 2. Larto Lake[9] is an old Mississippi River ox-bow. Its width and depth, as well as radius of curvature, are those of the active Mississippi. At its upstream end is a delta of the type most common to

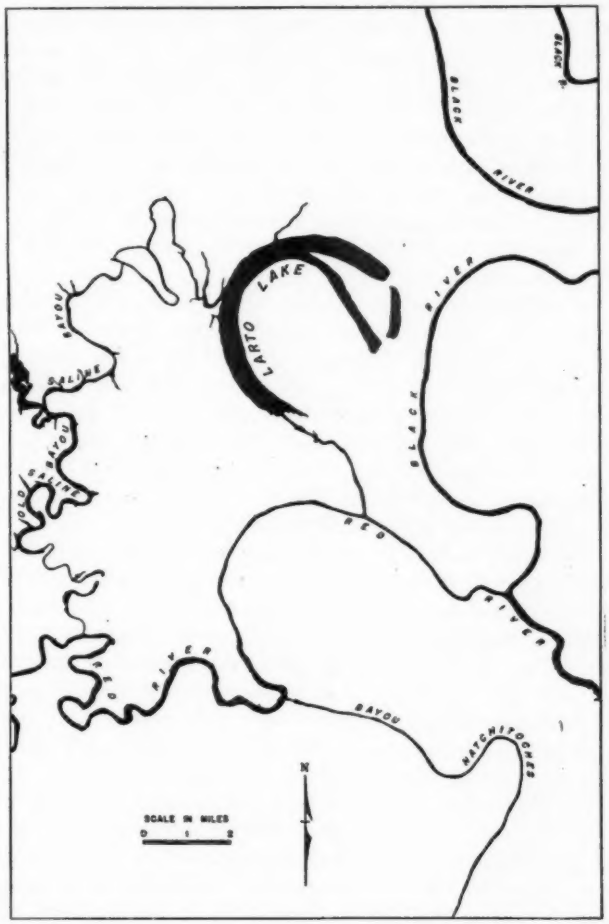

FIG. 2.—Active and abandoned channels of Red River and abandoned channels of Mississippi in alluvial valley of central Louisiana. Taken from U. S. Army, Buckeye and Tooleys quadrangles.

[9] R. J. Russell, "Larto Lake, an Old Mississippi River Channel," *Louisiana Conservation Review*, Vol. 3 (1933), pp. 18–21, 46.

Mississippi ox-bows. The preservation of this interesting relic, 15 miles removed from the nearest point along the active Mississippi, has depended on isolation from sources of alluviation. The levees along Black River have protected it from Mississippi silting. Low land toward Catahoula Lake collects deposits from smaller streams in the vicinity, preventing alluviation of Larto Lake. Artificial levees along Red River, however, have now upset this natural immunity from alluviation and flood. The whole region just north of Red River is now subject to backwater flooding year after year; alluviation is taking place so rapidly that forests are being killed as a consequence. Not many years ago, the natural levees along Larto Lake supported a prosperous farming population, who maintained a Post Office. Flood conditions have become so aggravated that the last resident left the region two years ago.

An additional reason for interest in Larto Lake is to be found in its having served as a junction point between Red and Mississippi rivers. Harold N. Fisk[10] has recently traced an old Red River channel along Old Saline and Saline bayous into Dry Larto, Larto, and several other bayous, now forming a maze not wholly indicated in Figure 2, and, eventually, into Larto Lake, on the western side of the bend. Low-water stages are shown in the figure. The break in Old Saline Bayou is evidence of channel deterioration. At high water, this whole old Red River course is continuous.

The habit of the Mississippi in flowing along the bluffs of the eastern side of its alluvial valley and in turning eastward as soon as the upland region is passed is a circumstance of to-day rather than the reflection of some significant underlying cause. The river has shifted freely across its alluvial valley under the natural conditions of the immediate past, and may do so in the future, in spite of preventive measures undertaken by man. Not more than 2,000 or 3,000 years ago, the Mississippi followed a course along the western side of its lower valley. Part of this history is shown in Figure 3.

The origin of Bayou Teche, a tiny stream displaying the pattern of the Mississippi River along the western side of the alluvial valley, is shown in Figure 3. From meander patterns it is easy to identify the course followed by Bayous Wauksha, Courtableau, and Teche as an abandoned Mississippi River channel. It is also apparent that the course followed by Bayous Boeuf, Courtableau, Carron, and Mariecroquant belongs to another stream. That this stream is Red River may be demonstrated readily by tracing Bayou Boeuf continuously

[10] H. N. Fisk, "Geology of Grant and La Salle Parishes," *Louisiana Dept. Conservation Geol. Bull. 10* (1938).

upstream to the vicinity of Alexandria, where it joins the existing Red River channel. In the field, the contrast is striking between the

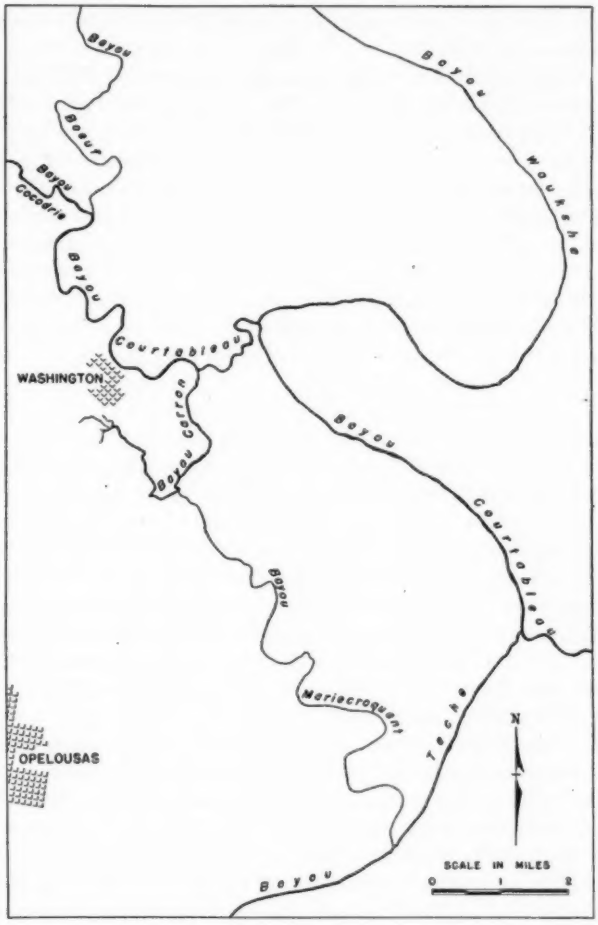

FIG. 3.—Origin of Bayou Teche, showing abandoned courses of Mississippi and Red rivers along western side of alluvial valley. Taken from U. S. Army, Opelousas and Palmetto quadrangles.

gray sediments of the old Mississippi levees and the bright red levees of the Red. The line of Red River levees extending down Bayou

Boeuf may be traced without interruption to a position between the Mississippi levees along Bayou Teche. Upstream, interrupted only by still more recent Red River levees in the area shown in Figure 2, the old Mississippi levees of Bayou Wauksha lead to the vicinity of Larto Lake.

The illustrations involving abandoned Mississippi and Red River channels are presented primarily for the purpose of demonstrating the use of meander patterns in deciphering flood-plain history. They have been stated in an elementary and greatly simplified form. Fisk, who is now intensively studying the surface of Rapides and Avoyelles parishes, in this region, has identified more than a dozen abandoned courses of Red River and has traced several old courses of the Mississippi for considerable distances along channels which have been omitted from Figures 2 and 3. His detailed statements will appear in a *Bulletin* of the Louisiana Geological Survey to be published in 1939.

NATURAL LEVEES

The natural levee is the dominant land form of the flood plain of a meandering stream. Its height is a measure of the stage difference between high and low water. Floods, under natural conditions, top it at many places and their alluvial deposits cause its growth. Its width depends on age and also the size of the parent channel. Large channels have wide levees, with comparatively gentle back slopes. Small channels have narrow levees, with steep back slopes. Natural levees are composed of finer materials than streams carry as bed load, because they are derived from materials carried in suspension, toward channel tops. Their constituents, however, are coarser than those of "back-swamp" flats at their rear.

The weight of a natural levee causes it to subside during growth. In the insecure foundations of an alluvial flood plain, more natural-levee material probably exists below the level of back-swamps than rises above it. Subsidence tends also to drag down the surface of the back-swamp in the immediate rear of a levee, so that it stands topographically lower than most of the back-swamp. These depressed areas have been called levee-flank depressions and ordinarily contain dense drainage nets or even more or less rectilinear ponds. Examples are shown on both sides of Bayou La Loutre, in Figure 4B. If a stream channel remains fixed in position for a great length of time and foundational conditions permit subsidence of its levees, the cross section of levee materials will be lenticular, with a greatly accentuated downbulge below the channel. Boreholes on Bayou La Loutre indicate that

this is the case. Horizontal migration of channels destroys the symmetry of their natural levees. Those on the inner side of a bend are wider and higher than those across channel, on the concave bank, opposite the point of a meander.

Natural levees determine occupance patterns in the alluvial parts of southern and central Louisiana. Population is relatively dense along levee crests, extremely sparse elsewhere. Roads and railroads, excepting where great sums of money have been expended to thwart the designs of Nature, are straight along reaches and turn with bends of streams. In places along Bayou Teche, parallel highways, each with a single row of closely spaced houses, flank either side of the stream, one set on each natural levee of the old Mississippi channel, another set on each natural levee of the Red.

Property lines follow designs attempting to give each owner his due share of levee crest, and hence run from stream bank to back-swamp. The original division of land was in terms of linear measure, the unit being an arpent along the river front, or "coast." Each arpent carried with it all the land back across the natural levee to the back-swamp, which was considered property common to all. Lacking precision in original boundaries, such land has more or less consistently been defined as extending back 40 arpents from the river when uncontemplated values arise in the back-swamp, such as the presence of a petroleum-producing salt dome. An arpent lacks about as many feet from 200 as the side of a square acre exceeds that value, so in southern Louisiana to-day we find that one term has been translated into the other, and the acre is a common measure of distance in rural sections.

The crest of a natural levee is favored not only by the possession of fairly coarse, and therefore easily worked, soils, well drained and relatively immune from flood hazards, but also by slight climatic advantages associated with its superior height. Air drainage causes slightly colder temperatures toward back-swamps on cold, still, clear winter nights, so the levee crest has fewer and slightly less severe freezes. In a region where some years escape a freeze entirely during the year and few years experience more than a dozen, a slight advantage of this sort is relatively important. The effect is more striking from the standpoint of fog. On crossing alternate strips of levee and back-swamp, along straight roads, such as that between Baton Rouge and Rosedale, in the Atchafalaya Basin on the west, it will be noticed on a great many nights that dense blankets of fog collect over the lowlands, whereas each climb to a levee crest is accompanied by thin fog, or clearing.

The occupance values along the natural levees of the reaches of a large stream are very much the same on either side of the channel. On bends, however, a considerable contrast arises, in favor of the concave bank, which is often known as the "coast" or "shore." The convex bank of the point is often known as the "island." Diverging property lines, attempting to run at right angles to the channel, favor the size of land holdings on the "coast," whereas converging boundaries pinch out and reduce holdings on the "island." Highways are likely to avoid long distances around points by cutting directly across narrow back-swamps from one concave "coast" to the next, leaving the "islands" off beaten tracks and relatively inaccessible. Artificial levees along the Mississippi do the same thing in many instances, abandoning the fine high land of points to floods raised abnormally high by artificial levees, and growing higher as the levee system becomes more perfect. Manchac Point, shown on the Baton Rouge Quadrangle (U. S. Army), has been thus abandoned by the construction of a new levee cutting directly from the town of Plaquemine to the "coast" of the next bend upstream.

Land becomes more valuable along ox-bows formed by cut-offs. The natural levees of such channels are no longer subject to shifting and are ordinarily protected by an artificial levee along the near side of the cut-off, so that stability and security replace the impermanence and hazard of position on the side of the main, meandering, active channel. False River, shown in Figure 4A, is a good example. The population along its natural levees is very dense compared with that on the levees of the near-by Mississippi River.

ABANDONED CHANNELS

After a river abandons its channel, deterioration sets in rapidly. Natural levees persist until regional subsidence narrows and lowers them under the encroachment of surrounding swamp or marsh accumulations. Even along the coast the amount of natural levee that disappears during a century is relatively small along an abandoned stream course. The channel itself in the course of a very few years narrows to such an extent that its original width is totally obscured. Two patterns reflect the process. In many cases a single channel is left to follow the crest of the now overfit natural levees of the original meander belt. In some places a relict channel follows along the inner side of each bank, just below levee crests. A pair of streams thus outlines the width of the original channel.

Bayou Lafourche, which departs from the Mississippi River at Donaldsonville, and continues to the Gulf along a more southerly

course than the present channel of the river, has natural levees fully as wide as those of the active Mississippi, and their pattern of meandering is thoroughly in keeping with the idea that they were formed by the whole discharge of that river not many centuries ago. The channel of Bayou Lafourche is distinctly underfit in terms of its levee pattern, and represents the type of abandoned channel maintaining a single course along the crest of the levees of a larger original stream.

Bayou Plaquemine, the next right-bank distributary of consequence upstream from Bayou Lafourche, and another abandoned main channel of the Mississippi River, exhibits the parallel-channel type of deterioration. It is shown on the Baton Rouge, Grosse Tete, and Osca Bayou quadrangles. At the town of Plaquemine, two bayous, Jacob and Plaquemine, leave the Mississippi and flow along parallel courses ½ mile apart. Though the courses are quite straight, each little bend in one is accompanied by a similar bend in the other. Evidence that this pair of channels represents a course of the Mississippi River somewhat more ancient than its course down Bayou Lafourche, and that it antedated the existing course past New Orleans, has been presented elsewhere.[11]

Channel deterioration may be studied very effectively along courses cut off at known dates within the historical period. Cane River, which flows past the town of Natchitoches, in northwestern Louisiana, was the main channel of Red River until a cut-off occurred in 1836. Its channel at present could accommodate only a small fraction of the discharge of the near-by Red. Deterioration has been of the single channel type. Examples of this kind teach one to use meander patterns and natural levee widths, paying practically no attention to channels themselves, in reconstructing flood-plain history. The channel of the Mississippi at Port Hudson, not far north of Baton Rouge, where Lyell, about a century ago, found old cypress logs beneath coastal terrace deposits, is now so obscure that one would hardly venture, without historical backing, to identify it as more than an insignificant chute. It is very rarely that we find a Larto Lake, preserving an original channel section after the lapse of several centuries.

Complications in the development of parallel channels in deteriorating courses may be observed in Figure 4. False River cut-off occurred in 1722. Deltas formed at both ends of the ox-bow and continued to grow until beheaded by artificial levees, which were made

[11] R. J. Russell, "Physiography of Ascension and Iberville Parishes," *Louisiana Dept. Conservation Geol. Bull. 13* (1938), pp. 11–16.

effective about 50 years ago. The channel leading to the downstream delta is called The Chenal. It flows first on one side of the old Mississippi River course, then on the other, but avoids a central position, except where necessary in making its crossings. Grand Bay, near the Mississippi, is a lake in the depression between original Mississippi levees and those of The Chenal on three of its sides. For several miles, at the upper end of The Chenal, houses dot the crests of its own levees as well as those of the Mississippi and highways along the larger levees are supplemented by a road along the northern levee of The Chenal. At the northern end of False River, the tendency toward forming channels on each side of the old Mississippi is less striking, but is clearly indicated by the presence of tiny streams in those positions.

Below Yscloskey, on Bayou La Loutre, as shown in Figure 4B, a small channel now drains the space between Mississippi River levees dating from the time when the St. Bernard sub-delta was the main river outlet. This stream avoids positions central in the old channel. In crossing from the northern to the southern Mississippi levee, it has shifted position upstream, leaving ten or more diagonal scars marking old crossings. This upper end of Bayou La Loutre is supplemented at various places by tiny channels along the inner banks of the old levees.

CREVASSE AND DISTRIBUTARY CHANNELS

The natural levee and the crevasse exhibit the equivalent of a symbiotic relationship. Without channel confinement caused by natural levees, crevasses could not occur. Were it not for crevasses, natural levees would not be maintained and built to the height of flood crests. While it is true that natural levees extend under water, along outer sides of threads of turbulence occasioned by channel discharge into lakes or other bodies of quiet water, it is also true that levees rising above the height of surrounding swamps and marshes depend upon sedimentary nourishment resulting from overtopping at times of flood. Low levees, near the coast, are frequently overtopped along extensive crestlines, but upstream, where levees rise from 10 to more than 40 feet above low-water levels in channels, overtopping is primarily a matter of the crevasse. Reports to the contrary are exaggerations. Humphreys and Abbot, for example, state that during the flood of 1852, with the exception of that part of its course through the Avoyelles Hills, Red River overtopped its entire south bank below Alexandria. Such a statement means that crevassing took place at a hundred or more points. During the same flood, half a dozen

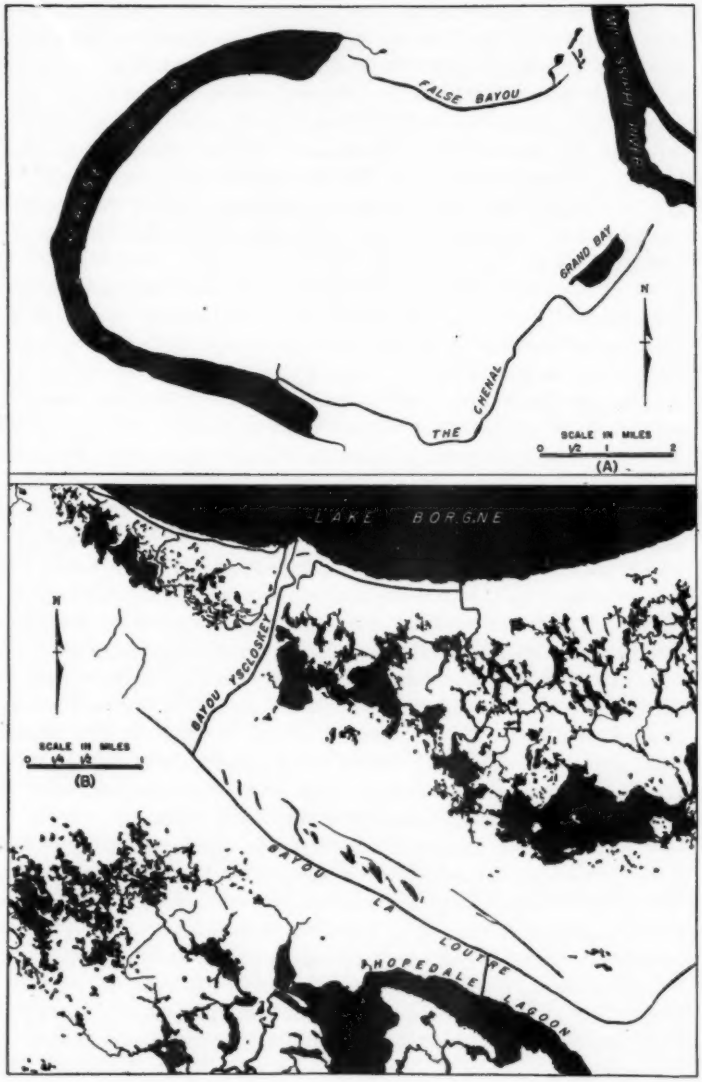

FIG. 4.—Parallel channels of abandoned courses. *A*. False River, cut off in 1722. Taken from U. S. Army, New Roads Quadrangle. *B*. Bayou La Loutre, ancient distributary of Mississippi. Taken from *U. S. Coast and Geodetic Survey Chart T-5315*.

crevasses were active along the Mississippi River within as many miles of the town of Plaquemine. One armed with the locations of these has difficulty in identifying them in the field to-day.

Under natural conditions, crevasses were numerous, occurred frequently, and, as a rule, were individually small. Rarely did they leave, in the natural levees of the lower Mississippi, a channel more than 4 feet deep after waters had subsided from flood crests. The angle of bifurcation at a crevasse is ordinarily high with respect to the thread of the current in the main channel, so the function of a crevasse is primarily that of alluviation, not scour.

A distinction should be made between crevasse channels and distributaries. The former are ephemeral, originating during floods, scouring a bit during initiation, filling as waters subside, and sealing themselves off when their levees and alluvial deposits reach or exceed the elevation of near-by natural-levee crests. Distributaries exemplify meandering tendencies. Owing to the steep gradient down the back slope of a natural levee, as compared with that down the main channel, and the abundance of the initial, suspended, and entrained load, gathered largely as the result of overtopping the levee, a crevasse channel tends to develop a channel section wide for its depth. Shoals and bifurcations result from the exaggeration of this cross-sectional characteristic, so that from a single point of outlet from the main stream, a crevasse channel branches downstream into numerous radiating channels, resembling those of an alluvial cone. It is unfortunate that the word, distributary, has been used both to describe these little branch channels and such large delta streams as the Atchafalaya River. Unless some substitute is found, it may become necessary to use qualifying adjectives or hyphenated nouns to designate and separate such stream types as crevasse-distributaries, on one hand, from delta pass-distributaries, on the other.

The permanent deposit of a crevasse channel is ordinarily located directly upon the natural levee of the stream from whence it issues. The typical distributary channel, on the other hand, continues to function for many decades or centuries and builds a levee system of its own, which reaches far beyond the natural levees of the parent river.

Few crevasse channels have ever become distributaries. Some distributaries are abandoned river main channels, such as Bayous Plaquemine and Lafourche. Other distributaries originated as crevasses, such as the Atchafalaya River and Bayou Manchac. It is because of this relationship that every gradation exists between crevasse and distributary; therefore the distinction, while highly useful, should not be pushed too pedantically.

The Atchafalaya River is the best example of an active distributary of the Mississippi River to-day. It originated as a crevasse several centuries ago, stagnated as a raft formed in its upper end, was rejuvenated when the raft was artificially removed, and is now functioning with such vigor that it is a decided threat to the permanency of the discharge past New Orleans.

The comparative youth of the Atchafalaya is indicated by cross-sectional and pattern immaturity. Deep, wide holes of bends alternate with narrow, shoal crossings in reaches. This condition reflects the increased discharge of the channel within recent years. If stability in discharge is attained, the channel will become better adjusted to its flow. Reaches will then be wider and the holes at bends will shoal to a considerable extent. The youth of the Atchafalaya is also indicated by the straightness of its channel pattern and immature meanders. The idea now and then advanced, that the Atchafalaya was once the main channel of either the Mississippi or Red is absolutely refuted by the condition of its channel and pattern of its meanders.

Downstream from the Atchafalaya junction with the Mississippi, are the channels of Bayous Fordoche, Maringouin, and Grosse Tete, all of which are intermediate in the series between minor crevasse channels and major distributaries. Each is flanked by its own natural levees for long distances through back-swamp. Each exhibits immature meanders appropriate to its size. For one reason alone, they may be better regarded as crevasse channels than as distributaries. Each of them has carried only a very small fraction of the discharge of the Mississippi River. No one of these channels offers sufficient gradient advantage over existing distributaries that it would have been a serious threat to the course of the river had it not been cut off by an artificial levee.

Bayou Manchac, a few miles south of Baton Rouge, is the distributary channel farthest upstream on the left bank of the Mississippi, and for that reason is part of the boundary of its active delta. After crossing the Mississippi levee, Manchac flows in a conspicuous cut valley across a Quaternary terrace, joining with the Amite River, of Maurepas Basin.[12]

New River, a few miles south of Bayou Manchac and the next left bank outlet of the Mississippi River, long functioned as either a distributary or as a crevasse channel. It crosses the same Quaternary terrace as Bayou Manchac, but very close to its hinge line, where the terrace passes from above to below the level of adjacent swamp. New

[12] F. B. Kniffen, "Bayou Manchac: a Physiographic Interpretation," *Geogr. Rev.*, Vol. 25 (1935), pp. 462–66.

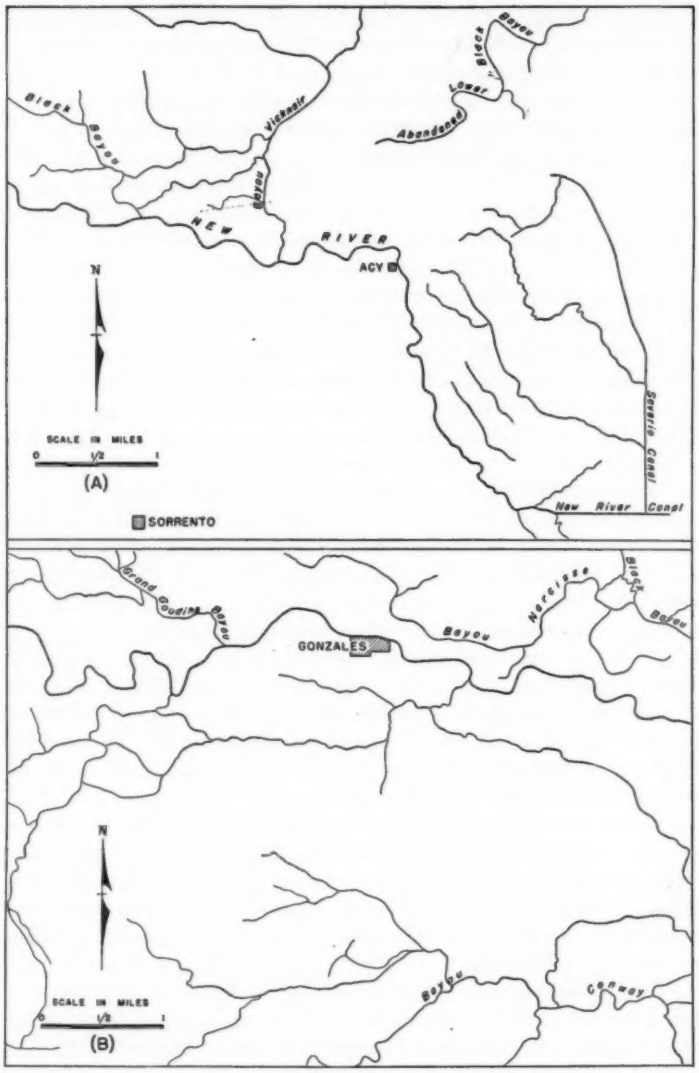

FIG. 5.—New River and related drainage. *A*. Crevasse-distributary patterns, toward Maurepas Basin swamps. *B*. Network patterns of Bayou Francois and effect of New River natural levees on drainage of surface recently tilted southeastward. New River passes Gonzales, Francois lies just to the south. Taken from *U. S. Geol. Survey*, Sorrento and Gonzales quadrangles.

River natural levees rise slightly above the elevation of the terrace. Whereas Manchac is in part erosional, New River exhibits only aggradational land forms.

New River resembles Bayou Teche in displaying more than one pair of natural levees. Both are of Mississippi River origin. An older, wider pair, with gentle back slopes, encloses a narrower, very recent pair, with steep back slopes. The stream with the wider natural levees was a distributary channel which functioned for a long period of time. The narrow pair of levees flanked a crevasse channel.

The course of New River is partially shown in Figure 5. Its distal end, shown in Figure 5A, exhibits crevasse-distributary patterns. West of Acy, New River exhibits many southward crevasse channels of small size, and the relatively important crevasse channel, Bayou Vicknair, to the north. Acy itself is a point of bifurcation from which crevasse distributaries radiate in several directions into surrounding swamp lowlands. Most of these crevasses have left alluvial deposits sufficiently large to bear roads and farm lands upon their surfaces. Many display only very minor channels, or none at all. Some of them are evident in the figure for the reason that their relict channels appear on the map. These crevasse distributaries are related to the older, wide levees of New River. The more recent, narrow New River turns south at Acy and its narrow levees extend far into the swamp. The meander pattern along this inner pair of levees includes bends much smaller and, for the most part, much less mature than those of the outer levees.

An extremely large number of crevasse channels may be identified on practically any of the U. S. Army quadrangles covering southern Louisiana flood plains. The White Castle Quadrangle shows a number of excellent examples leading from the Mississippi River, such as Bayou Goula, the stream leading past Bruly La Croix, or the headwaters of New River. Particularly interesting is the crevasse leading past Bruly St. Martin, with a mapped channel only at its far end, but with well outlined argicultural clearings extending along its several branches, far into back-swamp forest otherwise too poorly drained for agricultural use. Striking crevasses from Bayou Lafourche are shown on the Napoleonville Quadrangle.

The favored point for persistent crevassing, and the place where crevasse channels have the best chance of attaining the permanence demanded for distributaries, is along the concave bank of a meander, opposite a point. Bayous Manchac, Plaquemine, Lafourche, Fordoche, and Grosse Tete, as well as Atchafalaya and New rivers, all rise at such points. In accentuating its meanders, a stream adds land

to its bank along each point and erodes the natural levee of the opposite, concave bank. The levee crest is there lowered, so that frequent overtopping, or crevassing, is necessary to maintain the natural levee along all such "coasts."

Artificial levees are designed to prevent crevassing. As they become more and more perfect in accomplishing this purpose, they not only increase flood heights but also prevent the normal alluvial growth of natural levees. With increased flood heights, the danger of breaks through artificial levees also increases. When a crevasse in an artificial levee takes place, water flows out from the main channel with an artificially raised head, down an artificially steepened slope, and hence in abnormal amounts. Even under these conditions, crevasses are not likely to scour channels deep enough to divert any great amount of a river's permanent discharge. The main bulk of a river channel lies well below the levels of the back-swamp. The surface of a river rarely rises above the crest elevations of its natural levees. During the flood of 1927, the spectacular dynamiting of artificial levees at Caernarvon was not particularly successful in forming an effective outlet channel. Waters derived from the surface succeeded principally in forming alluvial deposits, such as are typical of crevassing, and of spillway operation in general.

BRANCHWORKS VERSUS NETWORKS

To William Morris Davis[13] are we indebted for the very useful pattern distinction between branchworks and networks. The dendritic stream of insequent drainage is a typical branchwork. Many limestone caverns present network patterns. Networks are quite typical of swamps and of many marshes. Channels in a network separate, only to become reunited downstream. The braided pattern of a shallow but wide channel is a special type of network. Much less regular in arrangement are the networks of the indecisive channels of flat, alluvial lowlands.

The Atchafalaya Basin presents many examples of stream networks. These may be seen on such quadrangles as Osca Bay, Chicot Lake, or Foster, all of the U. S. Army, Mississippi River Commission, survey. Active deltas being built into Osca Bay, Grand, and other lakes exhibit a network pattern of coarse-grained anastomosing. This is the perfect expression of the braiding tendencies of shallow streams heavily charged with silt. Remnants of this pattern are still evident in swamps far removed from open water to-day and indicate the

[13] W. M. Davis, "Origin of Limestone Caverns," *Bull. Geol. Soc. America*, Vol. 41 (1930), pp. 509 ff.

presence, and extent, of a large Atchafalaya Basin lake formerly occupying much of the lowland between Bayou Teche and Bayou Plaquemine. Typical swamp drainage patterns are networks in a more ordinary sense of the term. They may be seen in the minor basins, between distributary and crevasse natural levees, as in the Atchafalaya Basin, where the flat of the swamp prevents simplification of flow directions into a system of concentrated discharge, such as exists in a branchwork.

Figure 5B shows the drainage of a region where a swamp network is in process of being changed into a branchwork. Original drainage patterns are exemplified by Bayous Francois and Conway, both of which display networks. Such stream patterns originated in the flat of the swamp. Being now located in a position where regional tilting has lifted them slightly above swamp levels and has introduced a southeastward gradient, they are beginning to assume branchwork characteristics. North of New River the land is higher, slopes consistently, and branchwork development has reached a much later stage. Only decadent evidences of network patterns are now visible on the surface. Some of these may be seen, for example, on the Denham Springs Quadrangle, U. S. Geological Survey, east of the village of Prairieville, where divides are almost indeterminate and patches of upland swamp outline network patterns on the surface of the terrace.

Bayou Conway, of Figure 5B, is practically at the level of the back-swamp of the Maurepas Basin. The terrace on which it is located extends northward as far as Baton Rouge. Between its crossing by Bayou Manchac, not far north of Prairieville, and its disappearance below swamp deposits, this surface slopes with a gradient of about 2 feet per mile, or about four to six times as steeply as the active flood plain. The direction of slope is southeastward, toward the active lower delta of the Mississippi River. Those channels of the original swamp network leading in a southeastward direction have been favored by this direction of tilt and are now becoming the master streams of a branchwork in course of development.

Difficulties are encountered by streams between Prairieville and Bayou Francois in crossing the northern natural levee of New River, as it extends eastward across the southeastwardly tilted surface. Grand Goudine Bayou, Bayou Narcisse, and Black Bayou, all of which are shown in Figure 5, display patterns indicating levee interference. Each of these streams is forced to flow for a considerable distance along the lowland north of the New River levee before being able to discharge into New River or some other main channel. Bayou Narcisse is evidently older than the original New River, as it exhibits

a channel remnant south of New River levees, near the town of Gonzales. This part of its channel was beheaded as the result of New River alluviation. A similar example of beheading occurs in connection with Bayou Vicknair, a crevasse channel leading north from New River, near St. Amant. Black Bayou formerly continued into the channel, displaying its meander pattern north of Acy. Vicknair alluviation beheaded the lower part of the original Black Bayou and is now the stream into which the headwater portion of Black Bayou discharges. Aggradational piracy is quite as effective in beheading streams as is the more familiar piracy associated with headward erosion.

DENDRITIC PATTERN ON TERRACES

At least four terraces exist above the flood plains of central Louisiana. The surface of each of these is the product of alluviation similar to that of the active flood plains. Each terrace marks an oscillation in sea-level, apparently related to the lowering of all base levels during the withdrawal of waters from the oceans as Quaternary glaciers advanced, and a corresponding rise as glaciers retreated. They have been differentiated and preserved for the reason that regional tilting of the actively steepening northern limb of the Gulf Coast geosyncline has lifted them above flood-plain levels in central Louisiana, while burying them beneath swamps and marshes in the vicinity of the coast of the Gulf of Mexico. The New River area is the place where the lowest terrace of this type passes below Recent alluvium. H. N. Fisk, who has identified the known terraces of central Louisiana, has kindly furnished the map used here as Figure 6. From youngest to oldest, the terraces have been tentatively named, Prairie, Montgomery, Bentley, and Williana, each after a place of typical development, in the vicinity of the Colfax and Pollock quadrangles.[14]

It is typically, though not invariably, true that the branchwork of a small stream displaying a dendritic pattern is restricted to a single terrace. In the vicinity of White Sulphur Springs, in the lower right quadrant of Figure 6, the horizontal lines represent the lowest, youngest terrace, the Prairie. Of the many streams flowing toward the flood plain of Little River from the north and east, all but one are restricted almost entirely to the Prairie terrace. A similar pattern is exhibited by the Bentley terrace west and north of Pollock, near the southern border of the map. In general it is everywhere true that few channels cross from one terrace to the next in proportion to the

[14] Issued under the same name by both the U. S. Army and the U. S. Geological Survey. The former is decidedly better for the topography of the flood-plain area, but is deficient in lacking upland contours of the latter.

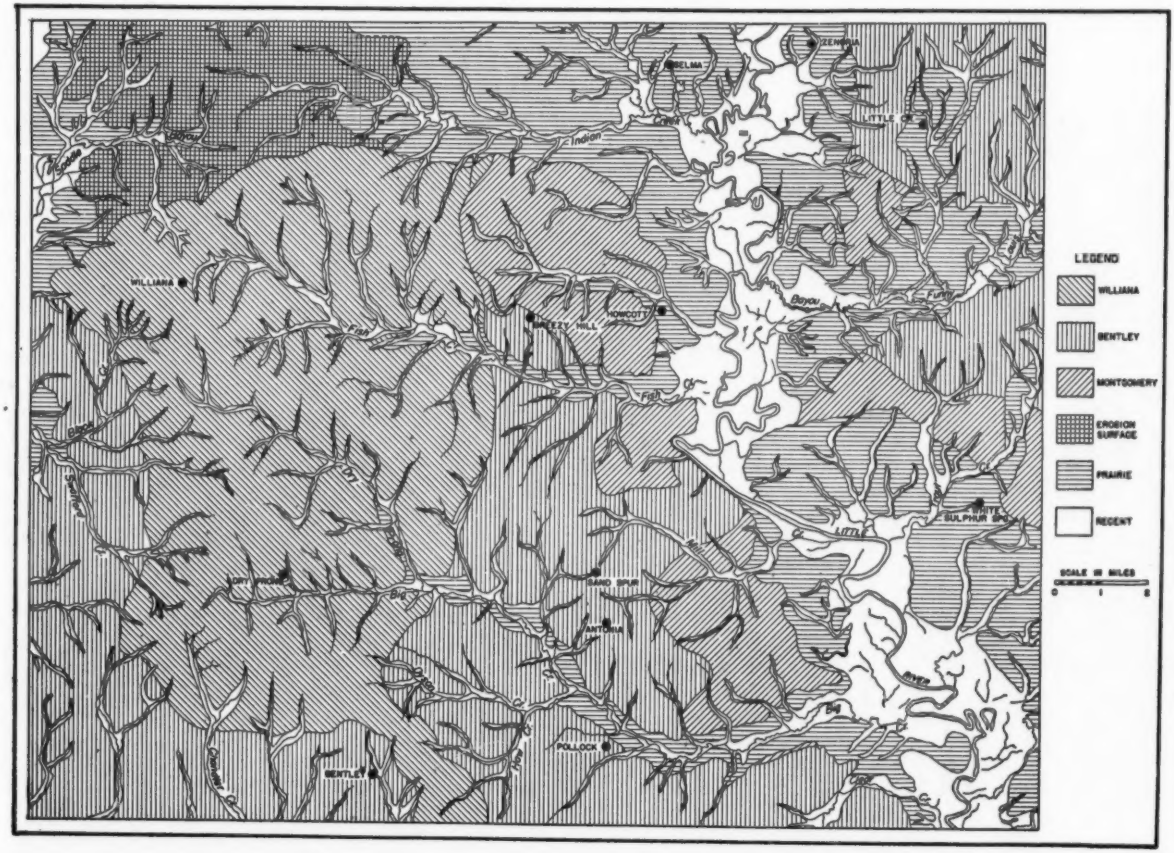

FIG. 6.—Insequent terrace drainage in central Louisiana, by H. N. Fisk. Taken from Colfax and Pollock quadrangles. This region is discussed more fully in *Louisiana Dept. Conservation Geol. Bull. 10.*

number of channels present on each surface concerned. In regions not covered by contoured quadrangles, this principle is of tremendous assistance in the identification of terrace boundaries.

The dendritic pattern of a terrace drainage branchwork, unlike the patterns of streams previously described in this paper, is the product of erosional activity. Sufficient time has elapsed since the uplift of central Louisiana terraces so that practically all traces of the aggradational patterns of their original flood-plain surfaces have been erased from their surfaces.

One of the last aggradational patterns to disappear as the result of flood plains becoming terraces is the drainage along the base of the old valley wall at the edge of the flood plain. Streams originate in this position as natural-levee alluviation forces them to the lowest part of the "rim swamp" along the side of the alluvial valley. Bayou Fountain, shown on the Baton Rouge Quadrangle, may be taken as the type example. For several miles south from Baton Rouge, it hugs the escarpment between flood plain and terrace, at the foot of the back slope of Mississippi River natural levees. Old River, east of Marksville, Bayou du Lac, west of Grand Côte, and other streams around the margins of the terrace remnant known as Avoyelles Prairie, shown on the U. S. Army Marksville, Bunkie, and Voorhies quadrangles, are excellent examples of rim-swamp streams. A suggestion of this pattern is also shown in Figure 6, toward the center of the map, where the tributary of Big Creek next east of Dry Prong hugs the escarpment between Williana and Bentley terraces for about 2 miles.

The natural levees of meandering streams of flood plains are still preserved, in decadent condition, on the lower terraces of coastal Louisiana.[15] Erosion has progressed so far in the higher terraces that such things as traces of original swamp networks, or the meandering natural levees of even master streams, have long since disappeared from the surface.

POINT STREAMS

The territory within each "point" of a meander belt is essentially a valley surrounded on all sides but one by a natural levee. Each of these valleys tends to develop a drainage branchwork of its own, ordinarily consisting of numerous very small tributaries and a single trunk stream capable of leading surface run-off into the adjacent back-swamp. Such systems may be called point streams.

[15] H. V. Howe, R. J. Russell, and J. H. McGuirt, "Physiography of Coastal Southwest Louisiana," *Louisiana Dept. Conservation Geol. Bull. 6* (1935), 72 pp.; also H. V. Howe and C. K. Moresi, "Geology of Lafayette and St. Martin Parishes," *ibid. Bull. 3* (1933), 237 pp.

Examples of point streams along the Mississippi River south of Baton Rouge include Bayou Paul, the point stream of Plaquemine Point, Bayou La Butte of Point Pleasant, Bayou Braud of Point Clair, Bayou Sigur of Philadelphia Point, Conway Bayou of Eighty-

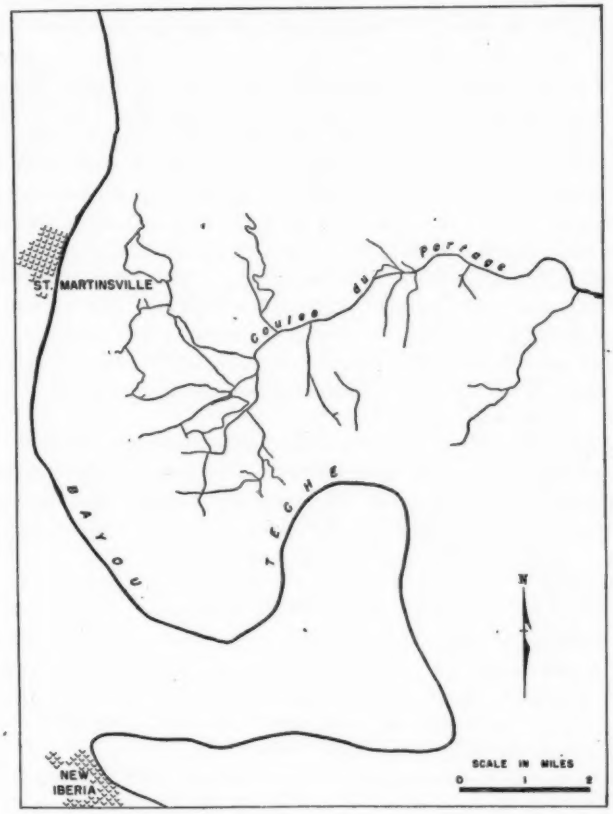

FIG. 7.—Coulee du Portage, point stream near Bayou Teche. Taken from U. S. Army, St. Martinville and Loreauville quadrangles.

one Mile and Sugar House points, and Bayou Verrette of Point Houmas.

Coulee du Portage, the point stream illustrated by Figure 7, is located behind the left-bank levee of Bayou Teche and leads into the lower part of the Atchafalaya Basin. The pattern is dendritic and the

stream is essentially erosional in origin. A swale of similar shape and size, under the climatic conditions of south-central Louisiana, will be occupied by a consequent stream exhibiting about this pattern whether the topography has resulted from degradational lowering or from aggradational construction. A gradual transition downstream leads Coulee du Portage into a swamp network, not shown in the figure.

As gentle slopes and small drainage basins distinctly limit the erosional possibilities of point streams, little material is available for alluviation downstream and natural levees are nowhere impressive along their courses. This condition is upset if one or more tributaries become crevasse channels and the drainage pattern is no longer that of a simple point stream. The crevasse channels ordinarily dominate the downstream patterns and for a period of time lasting well beyond that of active crevassing. Alluvial deposits, under such conditions, ordinarily block the normal point-stream drainage and convert the lowland within the point into swamp or marsh. For this reason it has become necessary to assist much point-stream drainage by artificial canalization. This will be noted along the Mississippi River at practically all the points mentioned.

The bending of natural levees around some points is so acute that isolated basins are formed which inhibit or entirely prevent point-stream drainage. This causes the formation of point lakes, several of which may be observed along the courses of Bayous Huffpower and Rouge, on the U. S. Army Bunkie Quadrangle.

SUMMARY

In the flood plains and marshes of Louisiana, streams are primarily associated with aggradational processes. The fundamental types of aggradational streams may be deep in channel section, in which case they meander, or shallow, in which case they braid. Stream patterns reflect both tendencies.

Meandering streams are the dominant type in the alluvial valleys. The width of meander belts is proportional to widths of channels and stream volumes. Old courses, though long abandoned, may be identified on the basis of patterns and the presence of natural levees. Tidal channels of the coastal marshes display more symmetrical meanders than the through streams of the flood plains.

Braiding occurs as the result of heavy load. This may be due to steep gradient but it also results from diminished current velocities, as in the distal portions of deltas. Crevasse channels leading down natural levees are the most typical braided streams of the flood

plains. A pattern of coarse-grained anastomosing is typical of delta accumulations in the lakes of the Atchafalaya Basin. A similar pattern accompanies the advance of rapidly alluviating streams in the lower Mississippi River delta.

The natural levees of meandering streams are the dominant land forms of alluvial valleys and coastal marshes. Cultural patterns and usages are determined by levee patterns. The deposits of braided channels to some extent also influence land use and occupance patterns.

In the basins between the natural levees of meandering streams, the dominant patterns are swamp networks. The streams exhibit indecisive flow, branching and reuniting in manners quite unpredictable.

Branchworks are typical of sloping surfaces above the active flood plains and are best displayed on upland terraces. Their patterns are useful in determining boundaries between adjacent levels. On lower terraces branchworks are being evolved out of old networks, terrace scarp streams, and meandering flood-plain channels. Their development is determined by uplift and regional tilting toward the active delta of the Mississippi River.

Branchworks are also displayed by degradational streams occupying the small shallow basins of points along major meandering stream channels. Limited drainage basins restrict their possibilities for development and most point streams are modified as a result of deposits derived from crevasses.

It is not presumed that this paper has been monographic in its treatment of Louisiana stream patterns. It has attempted to demonstrate a fair variety of patterns in a region topographically rather monotonous. In the course of investigation of stream patterns, it has become evident that Louisiana could be divided into significant physical divisions on the basis of this single criterion. The possibility that similar studies could be extended over broad regions, with equally significant results, is certainly worth investigating.

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VOL. 23, NO. 8 (AUGUST, 1939), PP. 1228-1245, 2 FIGS.

GEOLOGICAL NOTES

BASILOSAURUS IN ARKANSAS[1]

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On September 7, 1938, G. D. Harris, accompanied by the writer and her husband, E. L. Palmer, discovered a vertebra of the zeuglodont, *Basilosaurus cetoides* Owen, from the Jackson Eocene in the bed of a small western branch of Crow Creek, Crowley's Ridge, below the highway bridge, near Forrest City, St. Francis County, northeastern Arkansas, lat. 30° 00′ 18″. This is the first authentic reported find of *Basilosaurus* in that state. It corroborates definitely the Jackson Eocene[3] age determination of the Little Crow Creek beds of the same area and formation. The specimen was 13.7 inches in length, 7.4 inches in diameter, and weighed 46 pounds. It has been deposited in the Paleontological Research Institution, Ithaca, New York. A notice of the event was distributed from that institution by G. D. Harris[4] in December, 1938.

By a curious lapse of geographical exactitude on the part of numerous scientists, for example, Harlan,[5] DeKay,[6] Cope,[7] Woodward,[8] Hay,[9] Osborn,[10] and Gidley,[11] Arkansas has been included prematurely in the range of *B. cetoides* (Owen). Records of the species have been found heretofore only in Louisiana, Mississippi, Alabama, Georgia, and Florida.[12]

[1] Mansucript received, May 5, 1939.

[2] Paleontological Research Institution.

[3] L. W. Stephenson and A. F. Crider, *U. S. Geol. Survey Water-Supply Paper 399* (1916), pp. 73–78.

[4] *Christmas Greetings, Pal. Res. Inst.* (December, 1938).

[5] R. Harlan, *Geol. Soc. Pennsylvania*, Vol. 1 (1835), p. 348; *Med. and Phys. Res.* (1835), p. 349.

[6] J. E. DeKay, *Nat. Hist. New York*, Zoölogy, Pt. I (1842), Mammalia, p. 123.

[7] E. D. Cope, *Proc. Acad. Nat. Sci. Philadelphia*, Vol. 19 (1868), p. 155; *Amer. Nat.*, Vol. 24 (1890), p. 602.

[8] A. S. Woodward, *Outlines of Vertebrate Paleontology* (1898), p. 271.

[9] O. P. Hay, *U. S. Geol. Survey Bull. 179* (1902), p. 587. The Arkansas error was probably noted later by Hay for it is omitted in his checklist of 1930, *Carnegie Inst. Washington Pub. 390*, Vol. 2, p. 571.

[10] H. F. Osborn, *The Age of Mammals* (1910), p. 171.

[11] J. W. Gidley, *Proc. U. S. Nat. Mus.*, Vol. 44, No. 1975 (1913), p. 649.

[12] R. Kellogg, *Carnegie Inst. Washington Pub. 482* (1936), p. 272.

The original memorandum of *Basilosaurus* by Richard Harlan[13] stated that the fossils were found "on the Ouachita river, in the state of Louisiana, at a distance (south) of about fifty miles by land, and one hundred and ten by water from the town of Monroe in the parish of Ouachita, and in lat. 31° 46′ or 48′."

In 1835, Harlan[14] referred definitely twice to his first description but changed the wording of the fossil location to "the 'marly' banks of the Washita river, Arkansa territory." The expression "Arkansa territory" was converted by later authors into Arkansas. This change in itself would not have made the error in distribution because the southern boundary of Arkansa territory (1819) was the same as that of the state (1836), but Harlan was wrong in stating that the area, 50 miles south of Monroe, Louisiana, on the Ouachita (Washita) River was included in Arkansa territory.[15]

Richard Owen,[16] when describing *Zeuglodon* (a substitute name for *Basilosaurus*), combined cautiously Harlan's two descriptions of the same place and gave "Owachita or Washita river, Arkansas territory, in the state of Louisiana." In other citations Owen[17] merely quoted Harlan, giving "Washita river, Arkansas territory." The error is not that of Owen but of Harlan.

Regardless of the misidentification of the southern boundary of Arkansa territory, the sequence of references by Harlan is explicit so that one knows that he was defining a locality in the state of Louisiana. Later authors in adding Arkansas to the distribution of *Basilosaurus* did not verify by the original description. Since the northern strandline of the Jackson Eocene sea extended through northeastern Arkansas it was not unreasonable to suppose that zeuglodont bones would sometime be found in that state. However, not until more than 90 years had elapsed and after Harris uncovered fossil evidence, is the truth of the reiterated statement of the Arkansas extent of *Basilosaurus* substantiated.[18]

[13] R. Harlan, *Trans. Amer. Phil. Soc.*, Vol. IV, n.s. (1834), p. 397.

[14] R. Harlan, *ibid.* (1835), pp. 348, 349.

[15] *American Atlas*, 3d ed., H. C. Carey and I. Lea, Philadelphia, No. 35 (1827); W. R. Shepard, *Historical Atlas*, 7th ed. (1929), map 203; C. O. Paullin, *Atlas Hist. Geog.* U. S. ed. by John K. Wright, *Carnegie Inst. Washington Pub. 401* (1934), Pls. 62–63.

[16] R. Owen, *Trans. Geol. Soc. London*, 2d ser., Vol. VI (1842), [read 1839], p. 75.

[17] R. Owen, *Proc. Geol. Soc. London*, Vol. III (1842), [read 1839], p. 24; *Athenæum*, No. 585 (1839), p. 35 [Rept. of Geol. Soc.].

[18] Grateful acknowledgment is due Remington Kellogg, U. S. National Museum, for reading the manuscript and verifying the determination.

POTRERO HILLS GAS FIELD, SOLANO COUNTY, CALIFORNIA[1]

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Los Angeles, California

The Potrero Hills gas field is the fifth of a series of gas fields discovered in northern California. It is located in T. 4 N., R. 1 W., 40 miles northeast of San Francisco, approximately midway between San Francisco and Sacramento. The structure coincides in general with the topography of an isolated range of hills 5½ miles long and 2 miles wide which rises from adjoining alluviated and tidal lands of the Suisin Bay area. Its east-west trend is contrary to the general northwesterly trend of topography and structure in this area.

The structure, as indicated by surface mapping of the exposed Eocene and younger Tertiary formations, is an elongate eastward-plunging asymmetrical anticline with surface closure in its eastern part, and suggested closure at its western end due to possible cross faults or westward plunge.[3]

Paul P. Goudkoff, paleontologist, reported the following formations penetrated by the discovery well: undifferentiated Eocene, 2,562–2,928 feet; Paleocene, 2,928–3,077 feet; Upper Cretaceous, 3,088–5,334 feet.

One earlier well was drilled with cable tools in 1921 by the Honolulu Oil Corporation to a depth of 3,047 feet. Gas showings were reported, but the well was abandoned after considerable mechanical difficulty and several unsuccessful production tests.

The Rio Grande Oil Company leased the entire structure in 1931 on the basis of geologic mapping by Frank A. Morgan, chief geologist.

The leases were transferred to the Richfield Oil Corporation in 1937, and after additional field work a location was made 330 feet north and 660 feet east from the center of Section 10, T. 4 N., R. 1. W. The well was spudded in April, 1938, and was drilled and cored to a depth of 5,334 feet. After testing several lower sand beds, the hole was plugged to 3,265 feet and the well was completed, producing gas from 40 feet of Cretaceous sands between 3,225 and 3,265 feet. The initial daily production was 5 million cubic feet of gas through a 16/64-inch bean with 475 pounds tubing pressure and 990 pounds casing pressure.

[1] Manuscript received, June 16, 1939.

[2] Richfield Oil Corporation.

[3] A geologic map and a discussion of stratigraphy have been published by Thomas L. Bailey, "Geology of the Potrero Hills and Vacaville Region, Solano County, California, *Univ. California Bull. Dept. Geol. Sciences*, Vol. 19, No. 15.

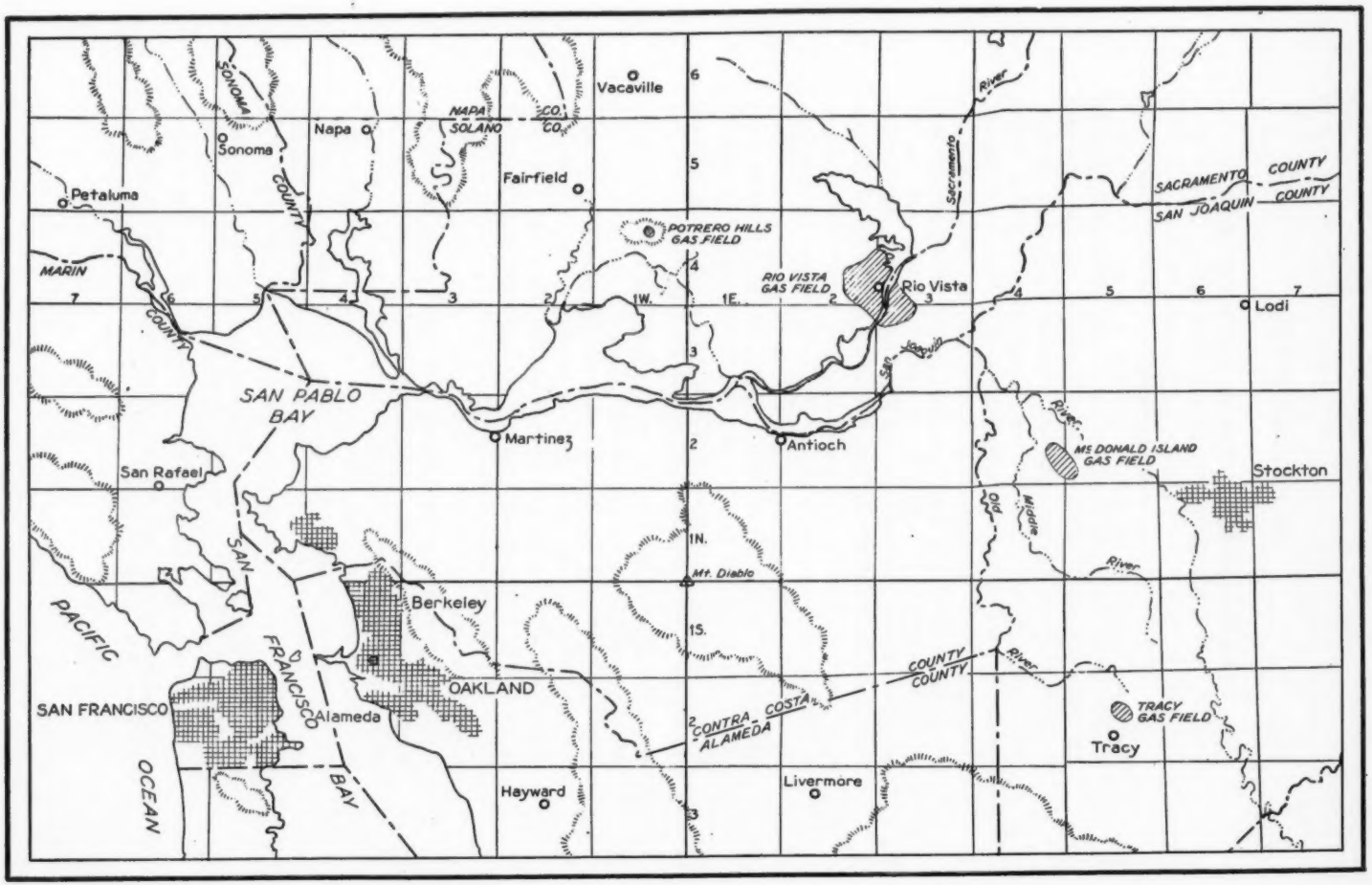
Vacaville
Napa
Sonoma
Petaluma
Fairfield
NAPA
SOLANO
CO.
CO.
SONOMA
COUNTY
MARIN
COUNTY
POTRERO HILLS
GAS FIELD
RIO VISTA
GAS FIELD
Rio Vista
Lodi
Sacramento
River
SACRAMENTO
COUNTY
SAN JOAQUIN
COUNTY
San Joaquin
River
SAN PABLO
BAY
Martinez
Antioch
MC DONALD ISLAND
GAS FIELD
Stockton
Old
Middle
River
San Rafael
SAN
PACIFIC
OCEAN
Mt. Diablo
Berkeley
OAKLAND
SAN FRANCISCO
Alameda
FRANCISCO
BAY
CONTRA COSTA
ALAMEDA
COUNTY
COUNTY
River
TRACY
GAS FIELD
Tracy
Hayward
Livermore
1W.
1E.
1N.
15.
2
3
4
5
6
7

FIG. 1.

PHYSIOGRAPHIC SIGNIFICANCE OF LOESS NEAR McPHERSON, KANSAS[1]

JOHN C. FRYE[2]
Wichita, Kansas

The origin of the so-called Equus beds of south-central Kansas has been of considerable interest for the past 50 years. The area covered by these deposits embraces parts of McPherson, Harvey, Marion, and Sedgwick counties, and lies between the valleys of the Smoky Hill and Arkansas rivers. The various ideas concerning the physiographic development of this area were summarized and discussed by Haworth and Beede[3] in 1897. The deposits have been generally considered to be of fluvial origin. The depositing agent was described as a through-flowing stream that diverged from the valley of the present Smoky Hill River near Lindsborg, at the point where that river now swings sharply from a southeast to a northeast direction, and flowed south to a point west of McPherson. From this point the river flowed south-southeast and joined the former Arkansas River northwest of Wichita. The main objection to the explanations advanced heretofore has been the presence of the so-called McPherson Ridge. This ridge comprises a divide between the drainage basins of the Smoky Hill River on the north and the Araknsas River on the south. Its crest is approximately 100 feet above the flood plain of the Arkansas valley and nearly 200 feet above the flood plain of the Smoky Hill valley. If the "Equus beds" were deposited by a through-flowing stream, it would seem that the stream in order to cross this ridge must have been at a level about 200 feet above the flood plain of the present valley of the Smoky Hill. It was noted by Haworth and Beede, however, that terraces indicating such a history were not found in the valley of the Smoky Hill River or of the Arkansas River.

During the season of 1938 the present writer was engaged in a ground-water investigation of the "Equus beds" area for the Geological Survey, United States Department of the Interior, in coöperation with the Kansas Geological Survey and the Division of Sanitation of the Kansas State Board of Health. During the course of this work he had the opportunity of making some observations along the "McPherson Ridge," and of examining many well logs from the area. On the

[1] Manuscript received, June 1, 1939. Published with the permission of the director of the Geological Survey, United States Department of the Interior, and of the director of the Kansas Geological Survey.

[2] United States Geological Survey.

[3] Erasmus Haworth and J. W. Beede, "The McPherson Equus Beds," *Kansas Geol. Survey*, Vol. 2 (1897), pp. 285–96.

basis of this study it was found that the "McPherson Ridge" is composed largely of eolian loess. As indicated by the well logs the loess in this locality reaches a maximum thickness of more than 110 feet, and from surface observations it is believed to cover an extensive area.

The recognition of an eolian origin for this interstream appears to remove the objections to the idea that the underlying "Equus beds" were deposited by a stream flowing from the Smoky Hill to the Arkansas Valley. The source of the loess has not as yet been determined with certainty. The loess is light reddish tan in color, is not stratified, contains bands of calcium carbonate nodules, and has the appearance of an eolian deposit. Two mechanical analyses of loess from western McPherson County are given in the following table.

MECHANICAL ANALYSES OF LOESS, SW. ¼, SEC. 27, T. 18 S., R. 4 W.
(Analyses by V. C. Fishel, Geological Survey, United States Department of the Interior, Washington, D. C.)
Percentage by Weight

	0.5–0.25 *Mm.*	0.25–0.125 *Mm.*	0.125–0.062 *Mm.*	0.062–0.005 *Mm.*	<0.005 *Mm.*	*Carbonate Lost by Decomposition in Dil. HCl*
1	0.7	1.0	2.7	55.1	28.5	12.0
2	0.9	1.2	2.3	53.1	28.4	14.1

Along the present streams of the area there are deposits of silt that closely resemble the loess but which are bedded. The writer believes these were deposited while the streams were overloaded with silt derived from the loess. The fact that these streams have since cut channels into this silt appears to indicate that it was laid down during and immediately after the deposition of the loess. The present drainage pattern has existed since the close of this loess deposition.

There are deposits of volcanic ash in northwestern McPherson County near the crest of the major divide. The absence of bedding in the ash, the fine granular appearance, and the fact that locally it grades upward into loess and is underlain by loess, is consistent with eolian deposition on a land surface in this locality. Some of the ash that occurs at a lower altitude immediately above stratified sands was probably deposited in water.[4]

As for the age of the loess, the writer feels justified in saying only that it is younger than the "Equus beds" beneath it, and that the lower part of it is older, and the upper part younger, than the ash deposits near the crest of the "McPherson Ridge."

[4] Kenneth K. Landes, "Volcanic Ash Resources of Kansas," *Kansas Geol. Survey Bull. 14* (1928), p. 31.

LOG OF WILDCAT WELL IN PENNINGTON COUNTY, SOUTH DAKOTA[1]

MAX LITTLEFIELD[2]
Tulsa, Oklahoma

In 1931 the Gypsy Oil Company (now the Gypsy Division of the Gulf Oil Corporation) drilled a wildcat test in the NE. ¼, SW. ¼ of Sec. 28, T. 3 N., R. 13 E., Pennington County, South Dakota. The location was 13 miles north and 1½ miles east of the town of Wall. The test was commenced on May 2, 1931, and completed on November 11, 1931. Rotary tools were used to a depth of 4,573 feet and cable tools from 4,573 feet to the total depth of 5,001 feet. The elevation, 2,956.8 feet, is given by the South Dakota State Geological Survey,[3] who published a résumé of the lithologic information furnished by the Gypsy Oil Company and a correlation list erroneously credited to a Gypsy geologist.

Following is a generalized description of the formations, together with data on casing points and occurrences of water.

Depth in feet	
	FOX HILLS SANDSTONE
	Surface to an undetermined depth. No samples were taken before setting surface pipe at the depth of 238 feet.
	PIERRE SHALE
238–1,900	Gray to gray-green shales with zones of siderite concretions, chalky shales, and thin interbedded bentonites
	NIOBRARA CHALK
–2,120	Gray to gray-green shales, some zones of which are highly chalky
–2,170	Chalk, shaly, gray to white
	CARLILE SHALE
–2,250	Shale, greenish gray; with small amounts of included silt and fine sand
–2,390	Shale, greenish gray; with interbedded layers of shaly siltstone and fine sand, as shown in cores taken from 2,266 to 2,276 and 2,347 to 2,358 feet. The latter core showed traces of gas
–2,470	Shale, dark gray. Zones of siderite concretions, included fine sand, and thin bentonites
–2,563	Shale, dark gray to black; with chalky spots. Zones of sideritic limestone concretions
	GREENHORN LIMESTONE
–2,575	Limestone, brown to gray, crystalline
	GRANEROS SHALE
–2,610	Shale, dark gray to black, calcareous; with chalky zones
–2,690	Shale, greenish gray; with glauconitic silt
–2,810	Shale, dark gray to black, chalky spots

[1] Manuscript received, May 19, 1939. Published by permission of the Gulf Oil Corporation.

[2] Gulf Oil Corporation.

[3] E. P. Rothrock, "Logs of Some Deep Wells in Western South Dakota," *South Dakota State Geol. Survey Rep. Investig. 4* (1936), pp. 28–30.

−2,875	Shale, dark gray to black; with many calcium carbonate concretions or thin beds of limestone
−3,024	Shale, greenish gray to black, in part silty and sandy; with zones containing thin interbedded fine sands and siltstones
	DAKOTA SANDSTONE
−3,082	Sand, interbedded layers of fine, medium, and coarse. Partings of carbonaceous shale. Interbedded shale layers from 3,047 to 3,082 feet. Fresh water rose 1,400 feet in the drill-stem tester in one hour from 3,026 to 3,041 feet
	FUSION SHALE
−3,154	Shales, gray, drab, and maroon, in part sandy
	MINNEWASTA LIMESTONE
−3,178	Interbedded shales and limestone. Limestones range from brown and sideritic to gray and crystalline
	LAKOTA SANDSTONE
−3,313	Shales, gray, with both included and interbedded silt and sand. Thirteen-inch casing cemented at 3,209 feet.
−3,323	Shale, dark gray; with interbedded gray to brown limestone
−3,407	Sand, medium, well sorted to 3,376 feet. Contains interbedded shale layers below that point. Fresh water rose 2,300 feet in drill-stem tester in one hour from 3,325 to 3,339 feet
−3,420	Conglomeratic sand, poorly sorted
	MORRISON SHALE
−3,460	Clay shales, red, brown, yellow, green, gray, and black
	UNKPAPA SAND
−3,488	Sand, fine to coarse; with pebbles as large as 4 millimeters in diameter. Clean and shale free. Fresh water rose 3,000 feet in drill-stem tester in 15 minutes from 3,461 to 3,475 feet
−3,530	Shales, gray to green, sandy; grading down into fine sand with green, pink, white, and brown interstitial clay
	SUNDANCE SERIES
−3,562	Clay and shale, green, glauconitic, sandy
−3,565	Limestone, gray-brown, dense
−3,767	Interbedded green shales, shaly glauconitic siltstones and sands with interstitial green clay
	SPEARFISH SHALE
−3,836	Sand and siltstone, white to pink, with interbedded red clay and shale
−3,950	Shale, red, gypsiferous
	MINNEKATA LIMESTONE
−3,980	Limestone, light brown, cream-colored, and pink; somewhat porous
	OPECHE SHALE
−4,082	Shale, red, in part silty; with a few thin beds of anhydrite
	PENNSYLVANIAN SERIES
−4,121	Limestone, dense, white to pink
−4,136	Shale, pink, calcareous
−4,204	Interbedded pink limestones, anhydrites, sands, and red and green shales
−4,220	Anhydrite; with interbedded dense brown limestone
−4,227	Shale, red and green
−4,240	Anhydrite, white
−4,251	Sands and shales, red and green, anhydritic
−4,276	Anhydrite, white
−4,315	Interbedded pink and brown limestones; red sand; and red and green shales
−4,337	Limestone, dense, pink, anhydritic
−4,390	Interbedded red and green shales, clayey sands, and anhydrite

−4,405	Interbedded pink limestone and anhydrite
−4,415	Shale, red and green, silty
−4,424	Limestone, red, and limy fine sand
−4,450	Interbedded limestones, brown to pink, and anhydrite
−4,455	Sand, poorly sorted, calcareous
−4,478	Interbedded brown limestone, white anhydrite and thin layers of sandy green shale
−4,517	Interbedded green shale, gray sand, and thin brown limestones
−4,532	Limestone, brown, dense; with chalcedony
−4,552	Interbedded brown limestone, sand, dark shales, and anhydrite. Some fragments of sand and limestone showed oil stain
−4,560	Limestone, brown; with interbedded dark shales. Some limestone fragments showed oil stain
−4,573	Anhydrite; with interbedded limestone. Changed to cable tools. Cemented 9-inch casing at 4,513 feet. No showing of oil or gas when plug was drilled. One-half bailer of dilute water per hour from 4,513 to 4,573 feet
−4,628	Limestone, brown to gray, silty, sandy; with interbedded thin dark shales and rare spots of anhydrite
−4,693	Interbedded clayey sand and siltstone and variegated shales
−4,725	Limestones, dense, white to pink
−4,734	Shales, variegated
−4,752	Shales, dark gray; with thin brown crystalline limestones
−4,812	Limestone, dense, white, brown, and pink; with partings of variegated shale
−4,830	Interbedded sands and shales. Sands poorly sorted, fine to coarse, hematitic. Shales variegated
	MISSISSIPPIAN SERIES
−4,850	Limestone, light brown, dense, cherty
−4,859	Limestone, dense, light brown; with chert, chalcedony, and secondary quartz. Cavernous porosity. Fresh water rose 3,850 feet in hole from interval 4,855 to 4,872 feet
−4,924	Limestone, dense, white to light gray, cherty
	PRE-MISSISSIPPIAN(?) DOLOMITE
−5,001	Dolomite, brown to pinkish, finely crystalline; with porosity between crystals and in small vugs. Seven-inch casing was set at 4,930 feet and fresh water rose 4,000 feet in the hole from 4,934 feet
−5,001	Total depth. Dry and abandoned

There are no specific age criteria for Pennsylvanian, Mississippian, and pre-Mississippian.

The anhydritic series below 4,082 feet is believed to be Pennsylvanian because it occupies the interval below red beds typical of the Opeche and because an evaporite facies of some part of the Pennsylvanian is present in tests in the Baker-Glendive area in Montana.

The limestones from 4,830 to 4,924 feet are termed Mississippian because of the consistent presence of chert and because the zone of porosity from 4,850 to 4,859 feet suggests solution below a major time break.

The age of the dolomite from 4,924 to 5,001 feet is questionable. It may be a unit of the Mississippian. It may be Cambrian, as dolomites of the same crystallinity and color occur in the Cambrian in northern central Kansas. However, such occurrences are ordinarily sandy and are believed to be a gradation of the Cambrian Deadwood

formation of the Black Hills. The dolomite from 4,924 to 5,001 feet contains no insoluble material.

MURALLA FIELD, DUVAL COUNTY, TEXAS[1]

J. W. SCHMOTZER[2]
San Antonio, Texas

The Muralla field is 8½ miles west and slightly north of San Diego, the county seat of Duval County. The discovery well of this field was drilled by J. B. Blanchard on the Atlee Parr tract, and is located 2,632 feet from the east line and 466 feet from the south line of the T. C. Rogers Survey No. 298.

In this well, the top of the Jackson was encountered at 3,491 feet, and the top of the *Textularia hockleyensis* zone at 3,740 feet. The well is producing from the Pettus sand, which is Cockfield in age. A hard sand cap was cored from 4,710 to 4,712 feet with oil sand below the cap from 4,712 to 4,715 feet, which is the total depth. The elevation of the well is 489 feet, derrick floor. Five and one-half-inch casing was cemented at 4,710 feet on the top of the sand cap. The initial production of the well was 22 barrels of oil per day, of 42.6° Bé. gravity, the well producing through a $\frac{3}{32}$-inch choke with a tubing pressure of 1,100 pounds, and a casing pressure of 1,500 pounds.

Accumulation appears to be due either to closure against, or immediately southeast of, a fault, downthrown on the southeast, or possibly as the result of a graben. The strike of the faulting is northeast. Due to lack of control, it is not possible to determine the exact location of the productive closure at this time.

[1] Manuscript received, June 5, 1939.

[2] Geologist, Arkansas Fuel Oil Company.

BEN BOLT FIELD, JIM WELLS COUNTY, TEXAS[1]

J. P. DAVIDSON[2]
Alice, Texas

The Bridwell Oil Company's M. W. Smith No. 1, discovery well of the Ben Bolt field, is located 330 feet south of the north line and 1,145 feet east of the west line of the Smith 976.5-acre tract in the La Trinidad Grant, 1½ miles southwest of the town of Ben Bolt, Jim Wells County, Texas.

[1] Manuscript received, June 1, 1939.

[2] Geologist, Bridwell Oil Company.

The well was completed on May 28, 1939, with an initial production of 145 barrels of oil per day, producing on $\frac{1}{8}$-inch choke; tubing pressure 875 pounds, casing pressure 1,000 pounds, and a gas-oil ratio of 500:1. The gravity of the oil is 42.5° Bé.

The producing sand occurs at a depth of 5,231–5,251 feet. It is lower Frio in age. The total depth of the well is 5,251 feet.

The nature of the structure appears similar to that of the East Alice field, located 4 miles northeast of the Smith well, and is probably a broad structural nose with closure on the west and northwest effected by faulting and probable lensing-out of the sand.

MAGNOLIA CITY FIELD, JIM WELLS COUNTY, TEXAS[1]

W. W. HAMMOND[2]
San Antonio, Texas

The new Magnolia City field in Jim Wells County, Texas, was discovered by Gillespie and Sons by the successful completion of their M. T. Shear well No. 1.

This well is 2 miles southwest of Magnolia City and $4\frac{1}{2}$ miles east of the village of Ben Bolt. The well, in the initial test on a $\frac{1}{8}$-inch choke produced 43.8° gravity oil at the rate of 108 barrels per day, with 1,500 pounds of flowing pressure. The production is secured from a 10-foot sand at a depth of approximately 5,450 feet. The sand appears to be a member of the Frio formation and lies approximately 280 feet above the top of the Vicksburg formation. The trap appears to be formed by the lensing of the sand against a structural nose.

[1] Manuscript received, May 18, 1939.

[2] Magnolia Petroleum Company.

TRINIDAD GEOLOGICAL CONFERENCE APRIL 18–27, 1939—ABSTRACTS[1]

H. D. HEDBERG[2]
Ciudad Bolivar, Venezuela

The Trinidad Geological Conference was held on the island of Trinidad, B.W.I., April 18–27, 1939, and was attended by approximately 40 geologists from Trinidad, British Guiana, the West Indies,

[1] Manuscript received, June 26, 1939.

[2] Mene Grande Oil Company, Apartado 35.

Group of geologists attending Trinidad Geological Conference, April, 1939.

Europe, and the United States. This conference was sponsored by the Petroleum Association of Trinidad with the coöperation of the oil companies and the Government of Trinidad. It is the third of a series of geological conventions held in this region in the last few years—the first being the Venezuelan Geological Congress in Caracas in 1937, and the second being the Venezuelan Geological Congress in San Cristobal last year.

The objects of the present conference were stated as follows.

1. To express to the Venezuelan Government the gratitude of the geologists of Trinidad for the generous invitations to the First and Second Venezuelan Geological Congresses; also to the oil companies operating in Venezuela for their liberal scientific contributions to these congresses.

2. To introduce the geologists of Venezuela to stratigraphical details of the geology of Trinidad on the assumption that interchange of knowledge will be of practical value to all.

3. To foster the good accord engendered by the Venezuelan Government in establishing closer coöperation and creating a spirit of mutual understanding between the two oil-producing countries on either side of the Gulf of Paria.

The major feature of the Conference was the series of excellently organized field excursions under the able leadership of Hans G. Kugler, chief petroleum geologist of the Central Mining and Investment Corporation, Ltd. These excursions occupied 6 days during which the attending geologists were taken over the whole island, visiting the classic fossil localities, points of critical stratigraphic importance, type localities and sections, and areas of special structural interest. These trips were made particularly enjoyable by the beautiful and varied natural scenery of the island.

Excursion No. 1.—Trinidad Northern Range, particularly the extreme northeastern part of the island. Greenstone intrusion of Sans Souci with surrounding Upper and Middle Cretaceous sediments—phyllites of southeastern slope of Northern Range—metamorphosed limestones of Hollis Water Reservoir where Jurassic ammonites have recently been found.

Excursion No. 2.—East-central part of island. Fossil localities in Upper Miocene-Pliocene Talparo formation and Miocene Brasso and Nariva formations—remnants of Middle Cretaceous limestones—equivalents of the Pointe-a-Pierre grits—coral and algal reef limestones of Biche and Tabaquite.

Excursion No. 3.—West-central part of island; vicinity of Pointe-a-Pierre and San Fernando. Classic type localities of Bon Accord conglomerate, San Fernando argiline, Pointe-a-Pierre grits, Mount Mo-

riah formation, Vista Bella and Point Bontour limestones, Cipero group, Springvale beds, *et cetera*.

Excursion No. 4.—South-central part of island. Mud volcano of Devil's Woodyard—fossil mudflows—Paleocene Marac Quarry limestone—remarkable study in contemporaneous deformation of Palo Seco beds along southern shore of island—classic Morne Diablo Quarry.

Excursion No. 5.—Southwestern part of island. Type locality of upper Forest Clay—Morne l'Enfer sands—La Brea formation—porcellanites due to burning of lignite beds—mud flows—famous pitch lake of Brighton.

Excursion No. 6.—Patos Island near Venezuelan shore. Phyllites and limestone of uncertain age.

Excursion No. 6 (alternative).—Forest and Apex oil fields.

The island of Trinidad has been subjected to intensive study by oil-company geologists for the last 30 years and proportionally much more stratigraphic and structural detail is available here than in most of the neighboring areas of the West Indies and South America. The Trinidad Conference furnished an excellent opportunity for the geologists of neighboring countries to share in the benefits of the geological progress on this island. However, because of the peculiarly complicated structure and rapid facies changes in this area, many points of structure and stratigraphy still remain to be solved and the visiting geologists were introduced to a number of intriguing and as yet unsettled problems.

Two days of the conference were devoted to the reading and discussion of papers. What little time remained between field trips and meetings was filled by a number of social affairs in which the guests and their families were very pleasantly entertained.

At the closing session on April 27 an invitation to the Third Venezuelan Geological Congress in 1940 was extended by Guillermo Zuloaga of the Venezuelan Servicio Tecnico de Geologia y Mineria.

There were fifteen members of the A.A.P.G. present at the conference and in their behalf gratitude and appreciation are here expressed to R. S. Mackilligin (inspector of mines and petroleum technologist); to H. G. Kugler who so ably conducted the field excursions and through whose efforts the Conference was largely brought into being; to A. G. Hutchison who assisted in the organizing of the excursions; to E. C. Scott, secretary; to N. Betancourt, C. C. Wilson, and A. E. Gunther of the organization committee; and to the many others who contributed to the success of the Conference.

ABSTRACTS

Papers presented at the 1939 Trinidad Geological Conference will be published in full during the year in both English and Spanish in the Venezuelan *Boletin de Geologia y Mineria* which may be obtained from the Servicio Tecnico de Mineria y Geologia, Ministerio de Fomento, Caracas. Brief abstracts of these papers are given here.

KUGLER, H. (Central Mining and Investment Corporation, Ltd.): Our Present Knowledge of the Geologic History of Trinidad.

In a brief but comprehensive review of the stratigraphy and geologic history of Trinidad the author touches particularly on recent discoveries and brings out the latest thought on the general geology of the island. He discusses the correlation of Trinidad formations with those of the mainland and calls attention to a number of unsolved problems in the stratigraphic succession of the island.

SCHMID, K. (Trinidad Leaseholds, Ltd.): The Classification of Rock Units and the Definition of Formations in Trinidad.

The principles of stratigraphic nomenclature are discussed, and group and formation names are suggested for Upper Tertiary stratigraphic units in the Fyzabad fields of southern Trinidad and in the northern basin and Central Range. These names are proposed tentatively for consideration and formal definition of the units is not attempted. Detailed stratigraphic charts are presented for both areas.

HUTCHISON, A. G., and TERPSTRA, G. R. J. (United British Oil Fields of Trinidad, Ltd.): A Note upon the Biche Quarry Limestone, Trinidad.

This limestone is one of a series of local algal and foraminiferal reef limestones in the Lower Miocene of the Central Range. The lithology, structure, and micropaleontology are discussed in detail and evidence for Lower Miocene age is given.

RENZ, H. H., and SUTTER, H. H. (Trinidad Leaseholds, Ltd.): The Pozon and El Mene de Acosta Type Sections of the Agua Salada Formation.

A type section is designated for the Agua Salada formation (Upper Oligocene to Middle Miocene age) of eastern Falcon, Venezuela, and the formation is defined and described. Particular emphasis is given to the foraminiferal fauna of this formation. The formation of the type section includes seven named foraminiferal zones with 144 species. The foraminiferal fauna of the Agua Salada is closely related to the fauna of the Carapita and Santa Ines formations of eastern Venezuela and to the Brasso and possibly the Springvale formations of Trinidad. The paper is accompanied by excellent maps, sections, and species distribution charts.

RUTSCH, R. (Natural History Museum, Basel, Switzerland): Evolution of Tropical American Tertiary Faunas and Theory of Continental Drift.

In this paper the author calls attention to the close relation between Paleocene and Eocene benthonic mollusks of northern Africa and tropical America. He believes this relationship is so close that the existence of an Atlantic Ocean in its present form is almost precluded as far as the oldest Tertiary is concerned. During the Oligocene and Miocene the differentiation is more clearly defined, the faunas more closely approaching their present individuality. The author concludes that while the close connections between the oldest tropical American and south European-North African Tertiary faunas can be explained by several theories, the continental-drift theory of Alfred Wegener is the most probable.

HUTCHISON, A. G. (United British Oil Fields of Trinidad, Ltd.): A Note upon the Jurassic in Trinidad, B.W.I.

Upper Jurassic ammonites (identified by L. F. Spath of the British Museum as *Perisphinctes transitorius* Zittel) were recently found in limestones interbedded with phyllites at the Hollis Reservoir on the south flank of the Northern Range of Trinidad. This is a discovery of major importance as definitely proving the Jurassic age of at least a part of the metamorphic rocks making up the Northern Range.

WILSON, C. C. (Trinidad Petroleum Development Co., Ltd.): The Los Bajos Fault of South Trinidad.

The Los Bajos fault of late Miocene or Pliocene age cuts across the southwestern peninsula of Trinidad with a strike of about North 70° West from Pt. Ligoure on the western coast to the vicinity of Negra Point on the southern coast. In its western part there is an apparent downthrow of 7,000 feet to the *south* while in its eastern part there is an apparent downthrow of 4,000 feet to the *north*. The author believes this fault to be essentially a strike slip fault with the northern side moving eastward relative to the southern side and the apparent throw at the fault line resulting from the discordant juxtaposition along the fault of folded structures developed previous to the fault movement. In the western part of its course the differential horizontal movement amounts to as much as 8 miles. The fault has played a major role in influencing the migration and accumulation of oil and its course intersects several major oil fields. The origin of this fault is explained by the author as due either to (1) "gravity collapse" of incompetent sedimentary filling of the Orinoco basin, or (2) crustal adjustment related to drift movement of the American continents.

GUNTHER, A. E., and TERPSTRA, G. R. J. (United British Oil

Fields of Trinidad, Ltd.): A Note upon Some Recent Additions to the Upper Cretaceous of Trinidad, B.W.I.

Upper Cretaceous deposits of cherts and marls have recently been discovered in the eastern part of the Central Range. Samples from these beds have yielded a foraminiferal fauna believed to be older than the Lizard Springs fauna described by Cushman and Jarvis and believed to be equivalent in age to the Mendez of Mexico.

SENN, A. (British Union Oil Company): The Paleogene of Barbados and Its Bearing on the History and Structure of the Antillean-Caribbean Region.

The author discusses in detail the stratigraphic sequence of Barbados.

Scotland formation (Lower and Middle Eocene)
Joes River formation (mudflow of Upper Eocene age)
Oceanic formation (Upper Eocene and Lower Oligocene)
Bissex Hill marl (Upper Oligocene)
Coral rock (Pliocene-Pleistocene)

Evidence is given for the ages assigned to these formations and correlation with other parts of the Caribbean region is discussed. The importance of Upper Eocene orogeny in the Caribbean region is stressed. A résumé is given of the geological history of the Antillean-Caribbean region in which it is concluded that during the Upper Cretaceous and Eocene a land or shallow water connection existed between the Caribbean and European Mediterranean regions but that this connection was broken during the Upper Eocene orogeny. A comprehensive correlation chart for the Caribbean region is presented.

SELF-FLUSHING BEAKER BRUSH[1]

W. FARRIN HOOVER[2]
Urbana, Illinois

The washing of a large number of beakers at frequent intervals in the process of routine analyses is facilitated by the construction and use of a special brush devised in the following manner. Three test-tube brushes are secured and the handles cut off approximately one inch above the bristles. These three brushes are then fastened with piano wire at intervals of 120° about the end of a heavy rubber hose 10 millimeters in diameter of any convenient length. The end of the hose is so placed that it is within one inch of the ends of the brushes.

[1] Manuscript received, June, 1939.

[2] Department of Geology, University of Illinois.

The hose when attached to a water faucet or outlet of a water pump completes the self-flushing beaker brush. The advantage of this type of brush is that the bristles of the brushes surrounding the orifice of the hose diffuse the water through the brushes so that particles of material adhering to the sides of the beaker are flushed out as rapidly as they are loosened by the manipulation of the brush. By using the brush described above it was possible for the writer to wash thirty-six 250-cubic centimeter beakers in 8 minutes even though the material to be removed had been thoroughly dried on the bottom and sides of the beakers.

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VOL. 23, NO. 8 (AUGUST, 1939), PP. 1246–1250

DISCUSSION

STRATIGRAPHIC STUDIES OF BAKER-GLENDIVE ANTICLINE, EASTERN MONTANA[1]

DISCUSSION BY DONALD M. ALLEN[2]
Wichita, Kansas

In this *Bulletin*, Vol. 23, No. 4 (April, 1939), pp. 461–75, appeared a paper by F. W. DeWolf and W. W. West, "Stratigraphic Studies of Baker-Glendive Anticline, Eastern Montana."

The writer had the opportunity of examining the samples during the drilling of the Northern Pacific No. 1, and had charge of the geological work on Smith No. 1, which was drilled 3,000 feet farther north. Although he is in agreement in many respects with the paper mentioned, he trusts that it will not be inopportune to submit some additional data and to offer some discussion and criticism. The stratigraphic section from the top of the Minnelusa to the Madison limestone is all that will be included in this discussion.

The correlations down to and including the Minnelusa have been agreed on by all interested parties. An erosional disconformity is evident at the top of the Minnelusa (Tensleep) for in the Northern Pacific No. 1, the top is 102 feet above the Amsden, while in Smith No. 1, it is 130 feet. The latter well had 8 feet of slightly weathered, white chert at the top, which was 28 feet higher stratigraphically and only 13 feet higher structurally. All the other formations down to the Madison limestone seem to have a conformable relationship.

The writer favors 5,733 feet and 6,380 feet, respectively, as the upper and lower limits of the Amsden in the Northern Pacific No. 1. This gives a thickness of 652 feet, which is not too great when compared with other sections. The Amsden in the Big Snowy Mountains and in the Black Hills is composed of limestones, sandstones, and red shales in varying amounts. It also contains gypsum, locally, and the red shales ordinarily occur in the lower part. DeWolf and West placed the top at 5,733 feet and the base at 6,115 feet. As a consequence, considerable red shale which is foreign to the subjacent Heath formation, at the type locality, would be included in it here. Since the base is more or less arbitrary, it would be better to put the section from 6,115 feet to 6,380 feet in the Amsden instead of the Heath.

The top of the Heath, the upper member of the Big Snowy group, can be lithologically placed at 6,380 feet where dark gray calcareous shales first appear. The characteristic feature of the Heath at the type locality in the Big Snowy Mountains, according to H. W. Scott,[3] is the "black petroliferous shales and sandstones." In the Northern Pacific, No. 1, the shales are not as plentiful and the sandstones are entirely absent, due to a change to limestone facies toward the east. Small amounts of dark gray shales appear in the cuttings down to 6,747 feet, and would seem to indicate that as the base.

[1] Manuscript received, June 26, 1939.

[2] 612 Orpheum Building.

[3] Harold W. Scott, "Some Carboniferous Stratigraphy in Montana and Northwestern Wyoming," *Jour. Geol.*, Vol. 43, No. 8, Part II (November-December, 1935), p. 1028.

The top of the Otter, the middle member of the Big Snowy group, is placed at 6,747 feet and the base at 7,575 feet. The Otter formation, according to H. W. Scott,[4] is composed of "a series of gray to green shales intercalated with oölitic and fossiliferous limestones." The shales, as in the Heath, are conspicuously absent in the Northern Pacific No. 1, due to their replacement by limestone toward the east. If the base of the Otter is at 7,165 feet, as DeWolf and West believe, a considerable amount of very oölitic and very fossiliferous limestones would have to be included in the underlying Kibbey, which is non-oölitic and non-fossiliferous at its outcrop. The writer can see no reason for dividing the Otter and Kibbey at that point.

The top of the Kibbey, the lower member of the Big Snowy group, is placed at 7,575 feet where an abrupt lithologic change occurs; the base, at 7,620 feet. The top might be as high as 7,530 feet. DeWolf and West have indicated the probable top and base at 7,165 feet and 7,440 feet, respectively. Scott's[5] description of the Kibbey at the type locality is "red shaly, unfossiliferous, marine sandstone containing a considerable amount of dolomitic and calcareous material." The zone from 7,575 feet to 7,620 feet, in the Northern Pacific No. 1, is composed of variegated, mostly red, silty to sandy, non-fossiliferous, very dolomitic shales. The only difference between the two sections is that the latter contains less sand, due to a change to non-clastic facies toward the east. It would be better, therefore, to include the limestones from 7,165 feet to 7,440 feet in the lower part of the Otter instead of the Kibbey.

The limits, as here set forth, would give the Heath 367 feet; the Otter 828 feet; the Kibbey 45 feet, and possibly 90 feet. The total thickness of the Big Snowy group would be 1,240 feet which compares favorably with a maximum of 1,200 feet in central Montana.

The writer would be much more inclined to place the top of the Madison at 7,620 feet than at 7,440 feet, on lithology alone. There is no evidence at 7,440 feet of an unconformity as is known to exist at the top of the Madison. Below the Kibbey, and sharply demarked from it, occur several hundred feet of slightly cherty, light-colored dolomites. The varying thickness, lateral extent, and composition of the section from 7,575 feet to 7,620 feet are suggestive of an erosional period, and it could hardly be considered a shaly zone in the Madison limestone.

[4] *Ibid.*, p. 1027.

[5] Harold W. Scott, *op. cit.*, p. 1025, Table IV, and p. 1026.

REPLY[1]

F. W. DEWOLF[2] AND W. W. WEST[3]
Urbana, Illinois, and Midland, Texas

Donald M. Allen's discussion of our paper published in the April *Bulletin* has been read with special interest because he assisted with the examination of samples from the three wells drilled by the Montana-Dakota Utilities Company. He probably did not know that the cores and cuttings from the Porcu-

[1] Manuscript received, July 27, 1939.

[2] University of Illinois.

[3] Skelly Oil Company.

pine Dome well (No. 4 of Figure 1 of our paper) were restudied by Mr. West in 1938 from 2,137 to 3,215 feet, and in part to 3,650 feet. The location of this well, midway between the Big Snowy sections and the Baker region, made it particularly important for correlation purposes. We desire to emphasize this log and also the fact that Mr. Allen makes no use of it. The parallel correlation lines between the logs of the Porcupine and Northern Pacific wells are considered significant and helpful. We again disclaim having satisfactory evidence for the subdivision of the Big Snowy group in eastern Montana but we do not think that the divisions advocated by Mr. Allen, which were considered and rejected by us, are preferable to those which we suggested.

We are in agreement with Mr. Allen that the top of the Heath formation may well be placed at the beginning of the dark gray to black shales in the Northern Pacific well (No. 5) but we call attention to the occurrence of such shales in the Porcupine well (No. 4) stratigraphically higher. We think these should be included in the Heath rather than the Amsden. A very satisfactory correlation exists between the sandstone beginning at 2,850 feet in the Porcupine well and the bed beginning at 6,115 feet in the Northern Pacific well. Since there are no dark shales above the sandstone in the N.P. well we consider that they were not deposited or were eroded, and that the top of the Heath is marked by the sandstone beginning at 6,115 feet. This interpretation included red shale in the Heath, as pointed out by Mr. Allen, but it seems necessary to choose either the absence of red shales or the presence of dark shales as the more important criterion. We prefer the dark shales but regard the decision as somewhat arbitrary.

Likewise the base of the Heath is questionable. Detailed laboratory examination showed dark gray shale in a core at 6,723 feet, and carbonaceous material in a core from 6,768 to 6,773 feet. Dark gray shale was found in cuttings from 6,788 to 6,793 feet. There was no marked abundance of dark shale with pronounced termination of it at 6,747 feet as implied by Mr. Allen. We favor including in the Heath the beds at 6,762–6,766 feet containing scolecodonts, but consider the decision somewhat arbitrary.

As to the boundary between the Otter and Kibbey formations in the N.P. well No. 1 and the Porcupine well, we suggest that a satisfactory basis for a decision is lacking because of the change in character of beds as compared with the Big Snowy type locality. If the type Kibbey sandstone is here represented by limestone, the fact that it contains fossils and oölites should not be considered objectionable. We can not agree that Mr. Allen's preference for 7,575 feet in the N.P. well as the top of the Kibbey is warranted in view of the presence of the Madison fossil *Straparollus* sp., at 7,490–7,493 feet. Nor do we think that the materials between 7,575 and 7,620 feet are incompatible with Madison age.

It is true that there appears to be no unconformity at 7,440 feet, where we think the Madison formation begins. Although such an unconformity exists in the Big Snowy Mountains in central Montana and elsewhere, it is entirely possible that none is present at Baker and that deposition was continuous, or only mildly interrupted from Madison to Kibbey. Absence of any good porosity in the Madison at Baker might well be ascribed to the lack of a pronounced break in deposition. On the other hand, the appearance of thick oölitic zones immediately overlying the Madison, as interpreted, may indicate some sort of change in conditions of deposition.

Materials similar to those recorded in the N.P. well from 7,575 to 7,620 feet, which Mr. Allen thinks unsuited to be included in the Madison, were found by Mr. West to be typical of the Pahasapa (Madison) 90 miles south of the N.P. well No. 1. Samples were examined from the Kennedy *et al.* Owens Trustee No. 1, a cable-tool well in Sec. 13, T. 52 N., R. 62 W., Rocky Ford field, Crook County, Wyoming. The Pahasapa was encountered at 795 feet and continued to the bottom of the well at 1,320 feet, and presumably to about 1,335 feet. A greenish gray to red shale break occurs from 923 to 938 feet. This, and the entire section, are believed to be correlative with the Madison as interpreted in the N.P. well. There are other localities at the north end of the Big Horn Mountains, where, according to Thom, red shale occurs in the Madison, but we particularly emphasize the Rocky Ford conditions because the samples were available for study by Mr. West.

We should like to repeat that the presence of Mississippian beds younger than the Madison and older than the so-called Amsden exist in eastern Montana with a thickness comparable with that of the Big Snowy group. The fossil evidence is consistent with this interpretation but is insufficient at present to justify a detailed correlation with the subdivisions of the Big Snowy group in the type locality. It is hoped that a record of the very careful study which has been made of the cores and cuttings from the wells under consideration will prove useful as more and more information becomes available from wells drilled in this area.

"PARK CITY" BEDS ON SOUTHWEST FLANK OF UINTA MOUNTAINS, UTAH

COMMENT BY HORACE D. THOMAS[1]
Laramie, Wyoming

The paper, " 'Park City' Beds on Southwest Flank of Uinta Mountains, Utah," by J. Stewart Williams, in the January, 1939, number of the *Bulletin*,[2] has given an understanding of the stratigraphy of the Permian Phosphoria formation in an area about which there has not been adequate information and, in addition, has cleared up many points regarding the enigmatic Park City formation.

The nomenclatural system used by Dr. Williams is, however, subject to criticism. He applies the name *Mackentire "red-beds" tongue of the Phosphoria formation* to a "westwardly thinning tongue of the 'red beds' "[3] and says that the Mackentire redbeds "represent a unit of deposition in which there is no apparent break below the main body of the Woodside shale"[4] and that there is "no essential and constant difference between the red shales and sandstones of the Mackentire tongue and those that constitute the main body of the Woodside."[5]

[1] University of Wyoming.

[2] *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 23, No. 1 (1939), pp. 82–100.

[3] J. Stewart Williams, *op. cit.*, p. 91.

[4] *Ibid.*, p. 93.

[5] *Ibid.*, p. 96.

According to the rules of stratigraphic nomenclature,[6] a tongue is a sedimentary unit of distinctive lithology which in one direction wedges out between beds of a different lithology but in the other direction becomes a part of a thicker body of sediments of identical lithology. Some time ago the writer described the intertongued relation of the Phosphoria and a redbeds facies (Chugwater) in central and eastern Wyoming and set forth the procedure he used in applying names to the Phosphoria and redbeds tongues.[7] This paper was perhaps overlooked by Dr. Williams.

Now, since the Mackentire tongue comprises redbeds, it must bear the name of the formation to which it is lithogically related, for it is not a tongue *of* the Phosphoria, but a tongue which *penetrates* the Phosphoria. In addition, the rules of nomenclature clearly state that *redbeds* is a valid lithologic term usable in connection with geographic names to make formal names of units,[8] and there is no necessity for placing it in quotation marks. Consequently, the proper designation for the unit named by Dr. Williams is *the Mackentire redbeds tongue of the Woodside.*

Under these circumstances the name Mackentire tongue can be used only throughout the area in which it is separated from the main body of the Woodside by a recognizable tongue of the Rex chert member of the Phosphoria. Dr. Williams carries the name beyond the limits of a tongue of the Rex, there draws the boundary between the Mackentire and the Woodside "arbitrarily at the top of the highest bed of gray shale," and points out that farther east "even that distinction may disappear."[9] At localities where the tongue of the Rex has thinned out but where the Mackentire is recognizable, the unit there is a *member* of the Woodside. However, where the Mackentire can not be differentiated from the Woodside, it is necessary to carry the name Woodside down to the base of the redbeds. The basal beds of the Chugwater differ in age over parts of Wyoming,[10] and it is entirely permissible for a formational name to change its scope from place to place in such a manner.

Further discussion of the use of the word, *redbeds*, seems warranted. To the writer, this is a concise, descriptive technical term which deserves greater usage. He has used the term in typescripts he has submitted to the *Bulletin* for publication, but editorial changes have been such that in print it appeared in hyphenated form or as two words. The rules of stratigraphic nomenclature were drawn up by a joint committee which was made up in part by representatives of the American Association of Petroleum Geologists, and it seems that we, as a body, should abide by the rules whenever possible. Remark j, Article 7, says, "Generally accepted petrographic or genetic terms shall be used for the lithologic part of a formation name; as *limestone*, . . . *redbeds*." It might well become the editorial policy, therefore, to use the single word, *redbeds*, instead of the four different forms the writer has found in relatively recent numbers of the *Bulletin:* (1) "red-beds," (2) "red beds," (3) red-beds, and (4) red beds.

[6] "Classification and Nomenclature of Rock Units," *Bull. Geol. Soc. America*, Vol. 44 (1933), p. 438.

[7] Horace D. Thomas, "Phosphoria and Dinwoody Tongues in Lower Chugwater of Central and Southeastern Wyoming," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18, No. 12 (1934), pp. 1655–97.

[8] "Classification and Nomenclature of Rock Units," *op. cit.*, p. 434.

[9] J. Stewart Williams, *op. cit.*, p. 96; Fig. 2, p. 84.

[10] Horace D. Thomas, *op. cit.*

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 23, NO. 8 (AUGUST, 1939), PP. 1251-1255

REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library and available to members and associates.

ELEMENTS OF GEOLOGY, BY W. J. MILLER

REVIEW BY A. N. MURRAY[1]
Tulsa, Oklahoma

Elements of Geology, second edition, by W. J. Miller. viii plus 524 pp., 367 figs. Cloth. 6.5×9.5 inches. D. Van Nostrand Company, New York (1939). Price, $3.50.

The second edition of this elementary text has been improved by the addition of illustrations, block diagrams, and new material. Replacement of pictures, data and ideas by new and more recent ones has brought the book up to date. The use of a better quality of paper has given the reproductions a much greater degree of definition and contrast than was possessed by those in the first edition.

In Part I, "Physical Geology," the chapter on "Instability of the Earth's Crust" constitutes Chapter II instead of Chapter V as in the first edition. The number of mineral species described has been reduced by half and confined almost entirely to rock-forming species. Additions have been made to the material on earthquakes, classification of igneous rocks, weathering, structure, wind and lakes. Chapter X, "The Sea and Its Work," has been thoroughly revised by rewriting and by the addition of about six pages of new material.

Part II, "Historical Geology," has been more extensively revised than Part I. The changing of the order of presentation of topics in numerous places as well as rewriting and the addition of new material has improved this part of the book. New material has been added to Chapter XV, "General Principles," and recent ideas on the origin of the earth have been placed in Chapter XVI. The chapters treating the different eras have been extensively revised. The ones on the Archeozoic and Mesozoic eras have been enlarged and almost entirely rewritten. The treatment of the Cenozoic structural and topographic history of different provinces in the United States is exceptionally good. Quaternary glaciation is treated in a separate chapter, "Quaternary Ice Age." The chapters on the life of the different eras have been given little revision with the exception of the one on "Cenozoic Life," in which the "History of Man" has been treated more extensively and largely rewritten. An appendix which contains "Organic Evolution" has been added to this edition.

This book, like the others by this author, is simply worded and clearly written. The use of many and apt illustrations, the employment of specific examples and the logically ordered presentation of the subject matter make this an excellent text for an elementary course in geology.

RECENT PUBLICATIONS

AFRICA

*"Explanatory Note on the Block Diagram of the Great Rift Valley from Nakuru to Lake Magadi," by Henry Gould Busk. *Quar. Jour. Geol. Soc. London*, Vol. 95, Pt. 2 (May 26, 1939), pp. 231–33; folded plate in colors.

[1] Professor of geology, University of Tulsa.

ARKANSAS AND OKLAHOMA

*"Ouachita Orogeny in Light of Geosynclinal Theory of Major Sedimentations," by Charles Keyes. *Pan-American Geologist*, Vol. 71, No. 5 (Geological Publishing Company, Des Moines, Iowa, June, 1939), pp. 359–68; 1 map.

BRAZIL

*"Petroleum in Brazil," by Otto Kennecke. *Petrol. Zeit.*, Vol. 35, No. 19 (Berlin, May 10, 1939), pp. 344–47; 4 figs., including geologic map and well log.

CALIFORNIA

*"Distribution of Foraminifera of the Genus Bolivina in Canada de Aliso, Ventura County, California," by Bradford C. Adams. *Amer. Jour. Sci.*, Vol. 237, No. 7 (New Haven, Connecticut, July, 1939), pp. 500–11; 1 fig.

COLORADO

Geologic Map of Powder Wash Dome, Moffat County, Colorado, by William B. Kramer and Robert McMillan. A few copies obtainable free, at U. S. Geol. Survey, Washington, D. C., and at 224 Custom House, Denver, Colorado. *Described in *U. S. Dept. Interior Press Release* (June 24, 1939); 2 pp.

ENGLAND

*"The Ammonite Succession at the Woodhan Brick Company's Pit, Akeman Street Station, Buckinghamshire, and Its Bearing on the Classification of the Oxford Clay," by William Joscelyn Arkell. *Quar. Jour. Geol. Soc. London*, Vol. 95, Pt. 2 (May 26, 1939), pp. 135–222; 4 text figs., 4 pls. of fossils, 4 tables.

FRANCE

*"Petrographic Study of Arenaceous Sediments of the Lower Cretaceous in the Southern Paris Basin," by André Vatan. *Bull Soc. Géol. France*, Ser. 5, Vol. 8, Nos. 5–6 (1938), pp. 161–70; 2 figs., 3 tables. In French.

*"Foraminifera of the Provençal Valanginien," by J. Pfender. *Ibid.*, pp. 231–42; 4 pls. In French.

GENERAL

*"Bibliographie des Sciences Géologiques," Vol. IX (1938). Published by the Geological Society of France with the coöperation of the French Society of Mineralogy. 344 pp. 6,258 titles, classified in 18 geological and geographic groups. Soc. Géologique de France, 28, rue Serpente, VIe, Paris (January 31, 1939). Price, 100 fr.

*"La marge continentale. Essai sur les régressions et transgressions marines" (The Continental Shelf. Marine Regressions and Transgressions), by Jacques Bourcart. *Bull. Soc. Géol. France*, Ser. 5, Vol. 8, Nos. 5–6, pp. 393–474; 16 figs.

**Oil and Petroleum Year Book, 1939*. Compiled by Walter E. Skinner. "The international standard reference work on the oil industry of the world." 416 pp., demy 8 vo., bound in red cloth. Particulars about 850 companies. Contains technical glossary, production figures, *et cetera*. Walter E. Skinner, 15, Dowgate Hill, Cannon Street, London, E. C. 4. Price, 11s. net, postfree.

The Mines Magazine (Colorado School of Mines Alumni Association, 734 Cooper Building, Denver, Colorado) Petroleum Edition (June, 1939) contains among others the following articles.

"The Injection of Gas into Oil Reservoirs," by H. L. Baldwin.

"Reflection Seismographic Work in California," by H. Hart Bradley.

"Old and New Aspects in Crude Oil Production," by I. S. Salnikov.

"The Oil Industry of Colombia, South America," by Phillip F. Shannon *et al.*

"A Subsurface Study of Ploog Pool, Central Kansas," by Arnold S. Bunte.

"The Continental Rosabell Ruby and Trojan Lotus Tests, Prowers County, Colorado," by Arthur B. Van Tine.

"Geophysical Prospecting in Kansas," by Maynard J. Trott.

"Acidation of Oil and Gas Wells," by M. E. Chapman.

"Oil Development in Illinois," by Bart DeLaat.

"The Seismic Reflection Method Comes of Age," by John Marr.

"Permian Development, 1938, West Texas Permian Basin," by Alden S. Donnelley.

"Gravity-Meter Prospecting for Oil," by W. W. Skeeters.

"Recent Trends in Geophysical Exploration," by A. L. Ladner and M. H. Billings.

"Water Flooding and Its Application in Northeastern Oklahoma and Southeastern Kansas," by R. C. Earlougher and L. M. Arnold.

**Atlantisheft II, Geologische Rundschau*, Vol. 30, Nos. 3–4 (Ferdinand Enke, Stuttgart, 1939), pp. 241–386; 20 figs., 5 pls. Special Atlantic region number. 25 articles and discussions from the Geological Association Convention at Frankfurt, January 7–8, 1939, including papers of a general nature, geophysics, geodesy, tectonics, vulcanism, earth history, paleogeography, paleontology, oceanography.

*"Triassic Fault-Line Deflections and Associated Warping," by Girard Wheeler. *Jour. Geol.*, Vol. 47, No. 4 (Chicago, May–June, 1939), pp. 337–70; 15 figs.

*"Enrollment in U. S. Mineral Technology Schools Nears 10,000," by William B. Plank. *Min. and Met.* (New York, June, 1939), pp. 298–99; 4 tables.

**Oil and Gas Developments: Year Book 1939*, by the National Oil Scouts Association of America (Houston, Texas). Edited under the direction of Charles Jefferson Bradley. 471 pp., maps, charts, tables. Review of 1938 developments. 8×10.75 inches. Cloth.

*"Our Oil Reserves and the Art of Prospecting," by E. DeGolyer. *Min. and Met.*, Vol. 20, No. 391 (New York, July, 1939), pp. 335–37; 1 photograph.

*"Petroleum Development and Technology, 1939," by the Petroleum Division. *Trans. Amer. Inst. Min. Met. Eng.*, Vol. 132 (New York, 1939). 625 pp., illustrations. Cloth. 6×9 inches. Papers and discussions presented before the Division at meetings held at San Antonio, October 5–7, 1938; Los Angeles, October 20–21, 1938; New York, February 13–16, 1939.

GERMANY

*"Microfauna of the Jurassic and Cretaceous, particularly of Northwestern Germany." Part 1: Lias α-ϵ, by C. A. Wicher. *Abh. Preuss. Geol. Landesanstalt*, New Ser., No. 193 (1938). 16 pp., 4 figs., 27 pls. In German.

*"The Geological Structure of the Styrian Basin and the Question of Its Productiveness of Petroleum," by Artur Winkler-Hermaden. *Petrol. Zeit.*,

Vol. 35, Nos. 22–23 (Berlin, June 7, 1939), pp. 389–97; 3 geologic sections and a geologic map.

GEOPHYSICS

*"Seismograph Prospecting for Oil," a symposium by Walter A. English, Willard H. Tracy, Arthur Nomann, Frank Ittner, and P. C. Kelly. *California Oil World*, Vol. 32, No. 12 (Los Angeles, 2d issue of June, 1939), pp. 3–14, and 42; illus.

GULF PROVINCE

"The Venericardia Planicosta Group in the Gulf Province," by Julia Gardner and Edgar Bowles. *U. S. Geol. Survey Prof. Paper 189-F* (1939), pp. 143–215, Pls. 29–46, Fig. 27. Supt. Documents, Govt. Printing Office, Washington, D. C. Price, $0.40.

ILLINOIS

*"Oil Possibilities of Deeper Beds in Illinois Basin," by Alfred H. Bell and George V. Cohee. *Oil Weekly*, Vol. 93, No. 13 (Houston, June 5, 1939), pp. 58–63; 2 tables, 1 map.

LOUISIANA

Oil and Gas Fields of the State of Louisiana. Map prepared by O. C. Postley and Jane Hanna. U. S. Geol. Survey with coöperation of the Louisiana State Department of Conservation and of oil and gas companies. Scale, 1:500,000 (1 inch = nearly 8 miles). 40×42 inches. Obtainable from the director of the Geological Survey, Washington, D. C. Price, $0.50.

MEXICO

*"Species of the Foraminiferal Family Camerinidae in the Tertiary and Cretaceous of Mexico," by R. Wright Barker. *Proc. U. S. Natl. Museum*, Vol. 86, No. 3052 (Washington, D. C., 1939), pp. 305–29; 12 pls. of fossils.

MICHIGAN

**Michigan Geology-Progress Bibliography, Pt. III*, by Duncan Stewart, Jr., Michigan State College Agriculture and Applied Science (East Lansing, May, 1939). 30 mim. pp. 490 items from *Rocks and Minerals*, 1926–1938; *Journal of Paleontology*, 1927–1938; *Bulletin of the Southwestern Association of Petroleum Geologists*, 1917; *Bulletin of the American Association of Petroleum Geologists*, 1918–1938; *Proceedings of the United States National Museum*, 1878–1938; *Bulletin of the United States National Museum*, 1875–1938; *The American Naturalist*, 1868–1938; *Smithsonian Miscellaneous Collections*, 1862–1938; *The American Geologist*, 1888–1905; *Transactions of the American Institute of Mining Engineers*, 1871–1918; *Transactions of the American Institute of Mining and Metallurgical Engineers*, 1919–1928; and additions, including papers for 1938 (Pts. I and II).

MISSOURI, IOWA, NEBRASKA, KANSAS

*"Oil Possibilities of the Forest City Basin," by John W. Merritt. *Petrol. Investor*, Vol. 3, No. 6 (Tulsa, June, 1939), pp. 5–6.

MOROCCO

*"The Age and Division of Certain Miocene Facies in the Prérif," by J. Lacoste and M. Rey. *Bull. Soc. Géol. France*, Ser. 5, Vol. 8, Nos. 5–6 (1938), pp. 305–20; 2 figs., 1 chart, 3 pls. Paris (March, 1939). In French.

*"Stratigraphic Distribution of Hantkenina in the Nummulitic of Rharb (Morocco)," by M. Rey. *Ibid.*, pp. 321–40; 5 figs., 3 charts, 1 pl. In French.

*"Preliminary Note on the Stratigraphic Division of Small Foraminifera in the Prérif Nummulitic (Morocco)," by V. Ostrowsky. *Ibid.*, pp. 341–53; 2 figs., 2 charts, 1 pl. In French.

PERU

*"Important Peruvian Area Opened by Aguas Calientes No. 1-A," by J. E. Brantly. *World Petroleum*, Vol. 10, No. 6 (New York, June, 1939), pp. 77–81; 6 photographs, 1 stratigraphic table, 1 well log.

TENNESSEE

*"The Howell Structure, Lincoln County, Tennessee," by Kendall E. Born and Charles W. Wilson, Jr., *Jour. Geol.*, Vol. 47, No. 4 (Chicago, May–June, 1939), pp. 371–88; 4 figs.

ASSOCIATION DIVISION OF PALEONTOLOGY AND MINERALOGY

**Journal of Paleontology* (Tulsa, Oklahoma), Vol. 13, No. 4 (July, 1939).

"Conodonts from a Bushberg-Hannibal Horizon in Oklahoma," by Chalmer L. Cooper.

"Significant Foraminifera from the Chickasawhay Beds of Wayne County, Mississippi," by A. D. Ellis, Jr.

"Bibliography and Index to New Genera, Species, and Varieties of Foraminifera for the Year 1936," by Hans E. Thalmann.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 23, NO. 8 (AUGUST, 1939), PP. 1256-1271

THE ASSOCIATION ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Executive Committee, Box 979, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

FOR ACTIVE MEMBERSHIP

James Gilmore Crawford, Midwest, Wyo.
T. F. Stipp, John R. Schwabrow, C. E. Dobbin
Glen Bernard Gariepy, Los Angeles, Calif.
W. D. Kleinpell, R. N. Ferguson, E. R. Atwill
Carl Herman Gerdes, Caracas, Venezuela, S.A.
A. I. Levorsen, J. C. Pollard, W. H. Emmons
Willis Charles Hatfield, Bogota, Colombia, S.A.
Frank B. Notestein, R. S. Breitenstein, J. Terry Duce

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Verner Jones, J. Rex McGehee, Lynn K. Lee
Louis de Agramonte Gimbrede, Austin, Tex.
Charles Nevin, H. Ries, Kenneth E. Caster
Jack Hastings Heathman, Wichita, Kan.
Charles E. Bradford, R. H. Beckwith, H. D. Thomas
Richard H. Hopper, Medan, Sumatra, N. E. I.
William S. W. Kew, U. S. Grant, Ian Campbell
Lee Knight Jordan, Stanford University, Calif.
F. G. Tickell, Eliot Blackwelder, A. C. Waters
Warren Douglas Sorrells, Maracaibo, Venezuela, S.A.
M. B. Arick, John G. Douglas, Frank J. Pospisil

FOR TRANSFER TO ACTIVE MEMBERSHIP

Alberto Lobo-Guerrero, Bogota, Colombia, S.A.
H. M. Kirk, C. A. Heiland, J. Harlan Johnson

ASSOCIATION STATISTICS

Year	Total Membership March 1	Annual Meeting Place	Total Registration Mems. & Non-mems.	Total Bull. Pages without Advertising	Annual Dues Mems.	Annual Dues Assoc.	Special Books; Notable Events	Total Assets
1916		Norman					A meeting of geologists of the Southwest	
1917	94	Tulsa		159	$ 5	$ 3	S.W. Assoc. of Petroleum Geologists	
1918	176	Okla. City		176	5	3		
1919	348	Dallas		445	5	3		$ 83.54
1920	543	Dallas		337	5	3		926.89
1921	621	Tulsa		724	10	6		3,582.76
1922	767	Okla. City		600	10	6	Mid-Year meeting, Denver	7,291.42
1923	901	Shreveport		730	10	6	Mid-Year meeting, Los Angeles	12,453.12
1924	1080	Houston		860	10	6		17,938.45
1925	1253	Wichita	825	1319	10	6	Pacific Section chartered	22,409.56
1926	1504	Dallas	1133	1339	15	8	Hdqtrs. estab. at Tulsa; Salt Dome Oil Fields; Mid-Year meetings, Denver & N.Y.	26,609.18
1927	1670	Tulsa	1827	1376	15	8	Index to 10 Vols.	29,810.40
1928	1952	San Francisco	386	1204	15	8	Theory of Continental Drift; Publ. Fund estab.	32,571.31
1929	2126	Fort Worth	1454	1612	15	10	Struc. Typ. Amer. Oil Fields; Sou. Tex. Sec. chartered	47,341.73
1930	2292	New Orleans	980	1610	15	10	Maracaibo Sec. and Paleon. Division chartered	61,751.60
1931	2562	San Antonio	1213	1522	15	10	Stratig. of Plains Sou. Alberta	74,043.43
1932	2558	Okla. City	894	1378	15	10	Geophysics Division chartered	63,782.07
1933	2336	Houston	1021	1568	12	8	Geol. of California	63,966.84
1934	2043	Dallas	1400	1737	12	8	Problems of Petrol. Geology	70,374.32
1935	1973	Wichita	1181	1868	10	6	Geol. of Nat. Gas; Max. Bull. pp. per $1 dues; Mid-Year meeting, Mexico	85,408.20
1936	2169	Tulsa	1847	1721	10	6	Geol. Tampico Region; Gulf Coast Oil Fields; Struc. Evol. Sou. Calif.	92,372.78
1937	2331	Los Angeles	1062	1641	10	6	Comprehensive Index; Geophysics Division dissolved; S.E.P.M. hdqtrs. at Tulsa; Mid-Year meeting, Pittsburgh	97,483.46
1938	2646	New Orleans	1706	1746	10	6	Miocene Stratig. Calif.; Mid-Year meeting, El Paso	102,096.03
1939	2951	Okla. City	1858		10	6	Peak membership; largest convention; Recent Marine Sediments	

ASSOCIATION COMMITTEES

EXECUTIVE COMMITTEE

HENRY A. LEY, *chairman*, Southern Cross Oil Company, San Antonio, Texas
ED. W. OWEN, *secretary*, L. H. Wentz (Oil Division), San Antonio, Texas
DONALD C. BARTON (deceased, July 8, 1939)
L. MURRAY NEUMANN, Carter Oil Company, Tulsa, Oklahoma
W. A. VER WIEBE, University of Wichita, Wichita, Kansas

REPRESENTATIVE ON DIVISION OF GEOLOGY AND GEOGRAPHY NATIONAL RESEARCH COUNCIL

FREDERIC H. LAHEE (1940)

FINANCE COMMITTEE

E. DEGOLYER (1940) WALLACE E. PRATT (1941) W. B. HEROY (1942)

TRUSTEES OF REVOLVING PUBLICATION FUND

RALPH D. REED (1940) GEORGE S. BUCHANAN (1941) E. FLOYD MILLER (1942)

TRUSTEES OF RESEARCH FUND

SAM M. ARONSON (1940) ARTHUR A. BAKER (1941) WALTER R. BERGER (1942)

BUSINESS COMMITTEE

L. C. MORGAN (1940), *chairman*, 358 North Dellrose, Wichita, Kansas

C. C. ANDERSON (1940)
H. K. ARMSTRONG (1941)
A. A. BAKER (1940)
W. A. BAKER (1939)
E. J. BARTOSH (1940)
N. WOOD BASS (1941)
A. H. BELL (1941)
J. BOYD BEST (1941)
L. D. CARTWRIGHT (1941)
J. I. DANIELS (1941)
R. K. DEFORD (1941)
C. E. DOBBIN (1941)
H. L. DRIVER (1941)
DELMAR R. GUINN (1941)
H. M. HUNTER (1941)
G. M. KNEBEL (1941)
HENRY A. LEY (1941)
P. W. MCFARLAND (1940)
C. C. MILLER (1941)
C. L. MOODY (1941)
L. M. NEUMANN (1940)
H. H. NOWLAN (1941)
ED. W. OWEN (1940)
VIRGIL PETTIGREW (1940)
PAUL H. PRICE (1941)
GAYLE SCOTT (1940)
H. B. STENZEL (1940)
W. T. THOM, JR. (1941)
W. C. THOMPSON (1940)
C. W. TOMLINSON (1941)
W. A. VER WIEBE (1940)
E. B. WILSON (1941)
W. B. WILSON (1940)
ROBERT H. WOOD (1941)
C. E. YAGER (1941)

MEMBERS-AT-LARGE

PAUL L. APPLIN (1940)
A. R. DENISON (1940)
J. V. HOWELL (1940)
MAX L. KRUEGER (1940)
JOHN L. TROXELL (1940)

REPRESENTATIVE TO MINNEAPOLIS MEETING GEOLOGICAL SOCIETY OF AMERICA

R. S. KNAPPEN, Gulf Oil Corporation, Tulsa, Oklahoma

ASSOCIATION COMMITTEES

COMMITTEE FOR PUBLICATION

R. E. RETTGER (1942), *chairman*, Sun Oil Company, Dallas, Texas

1940	1941	1942
CARL C. ADDISON	THOMAS H. ALLAN	CHARLES G. CARLSON
C. I. ALEXANDER	T. C. CRAIG	JAMES TERRY DUCE
GEORGE R. DOWNS	A. B. GROSS	COLEMAN D. HUNTER
HAROLD W. HOOTS	ROBERT F. IMBT	LEWIS W. MCNAUGHTON
J. HARLAN JOHNSON	J. T. RICHARDS	JAMES L. TATUM
A. M. LLOYD	J. MARVIN WELLER	FRED H. WILCOX
JOSEPH J. MAUCINI		
GRAHAM B. MOODY		

RESEARCH COMMITTEE

A. I. LEVORSEN (1942), *chairman*, 221 Woodward Boulevard, Tulsa, Oklahoma

1940	1941	1942
HOWARD S. BRYANT	E. WAYNE GALLIHER	N. WOOD BASS
W. C. KRUMBEIN	W. S. W. KEW	MONROE G. CHENEY
EUGENE MCDERMOTT	JOHN C. MILLER	RONALD K. DEFORD
C. V. MILLIKAN	D. PERRY OLCOTT	WINTHROP P. HAYNES
GAYLE SCOTT	BEN H. PARKER	ROSS L. HEATON
E. H. SELLARDS	WENDELL P. RAND	BELA HUBBARD
THERON WASSON	F. W. ROLSHAUSEN	T. E. WEIRICH

GEOLOGIC NAMES AND CORRELATIONS COMMITTEE

JOHN G. BARTRAM (1942), *chairman*, Stanolind Oil and Gas Company, Tulsa, Oklahoma

1940	1941	1942
PHILIP K. COCHRAN	MONROE G. CHENEY	JOHN E. ADAMS
GLENN S. DILLE	ROBERT H. DOTT	GENTRY KIDD
BENJAMIN F. HAKE	HAROLD N. HICKEY	HUGH D. MISER
R. M. KLEINPELL	MERLE C. ISRAELSKY	RAYMOND C. MOORE
C. W. TOMLINSON	WALTER K. LINK	

PERMIAN SUB-COMMITTEE

C. W. TOMLINSON (1940), *chairman*, 509 Simpson Building, Ardmore, Oklahoma

1941	1942
MONROE G. CHENEY	JOHN E. ADAMS
ROBERT H. DOTT	RAYMOND C. MOORE

COMMITTEE ON APPLICATIONS OF GEOLOGY

CARROLL E. DOBBIN (1942), *chairman*, U. S. Geological Survey, 224 Custom House, Denver, Colorado

J. CLARENCE KARCHER (1942), *vice-chairman representing geophysics*, 406 Continental Building, Dallas, Texas

CAREY CRONEIS (1942), *vice-chairman representing paleontology*, Walker Museum, University of Chicago, Chicago, Illinois

1940	1941	1942
B. B. WEATHERBY	HAL P. BYBEE	LUTHER E. KENNEDY
	E. E. ROSAIRE	EARL A. TRAGER
	HAROLD W. HOOTS	

COMMITTEE STUDYING METHODS OF ELECTING OFFICERS

WALTER R. BERGER, *chairman*, Trinity Building, Fort Worth, Texas

R. M. BARNES A. R. DENISON C. E. DOBBIN

METHOD OF ELECTING OFFICERS

HENRY A. LEY
San Antonio, Texas

Methods of nominating and electing officers are probably a matter of rather wide interest and concern in all organized bodies from time to time. This Association in the past has appointed committees to study this subject. Their reports have been published in the *Bulletin*. None, heretofore, has found it necessary or desirable to change the method first adopted by this Association.

At the Oklahoma City meeting the business committee and the Association authorized appointment of a committee again to make a study of methods of electing officers. That committee has been appointed and is now actively engaged in a comprehensive study. Their report with recommendations, if any, will be transmitted to your executive committee, which committee will in turn submit the report together with executive remarks, if any, to your district representatives with instructions that the reports be openly and frankly read and discussed in all affiliated societies.

There are a number of methods of nominating and electing officers that run the gamut from pure democratic forms to autocratic devices fashioned to perpetuate a hierarchy. Opinions concerning the most desirable method naturally vary according to the objective desired.

In all organized bodies and in all political economies, excepting only anarchism, there must be a governing group, consisting of a number of men set apart from the others and authorized to do certain things in the name of all. There are officers, committees, and chairmen; rules governing their election or selection; and the duties imposed upon them by constitution and by-laws. All these are machinery and functions—the business of organization government.

In our own organization, soon a quarter of a century old, it can be truthfully said, I believe, that we have grown steadily in a truly democratic sense with efficient and effective administrations. Consistent spontaneous action of the body whole is an idealistic objective, that is probably beyond the nature of human nature when it concerns administration or government.

Methods of electing officers are democratic or autocratic. Whatever the method it should be put in a form that is easily understood by all and frankly classed as democratic or autocratic. We now nominate officers from the convention floor and elect by ballots cast at the same meeting. We have not seen fit, thus far, to delegate officer nominations to a "nomination committee." By restricting the ballot to qualified voters present at annual meetings we are guilty of "taxation without representation." How our long established custom can be revised to continue freedom in nominations and balloting without finding ourselves in the unfortunate predicament of permanent cut-and-dried group control, is a matter of serious consequence. On the other hand we must acknowledge the soundness of the argument of those sincere members who hold that all members should be free to voice their convictions *via* the mail ballot.

COPY

June 9, 1939

Mr. L. Murray Neumann,
P. O. Box 801,
Tulsa, Oklahoma.

COMMITTEE APPOINTMENT
ELECTION METHODS
A. A. P. G. OFFICERS

Mr. Ed. W. Owen,
Milam Building,
San Antonio, Texas.

Mr. W. A. Ver Wiebe,
University of Wichita,
Wichita, Kansas.

Mr. Donald C. Barton,
P. O. Box 2180,
Houston, Texas.

The business committee and the membership of the A. A. P. G. have requested the president and executive committee to create a committee of five (5) to make a survey of methods of electing A. A. P. G. officers. The report of this committee should be available to the executive committee not later than November 1, 1939.

Comprehensive surveys have been made by former committees appointed to study election methods. Their reports are on file at Association headquarters. This file will be forwarded to your committee chairman, who in turn will forward the report to each committee member.

In a matter of such import and consequence as this, all parties concerned are deeply obligated to the membership-at-large of this Association. Next Spring we meet in our twenty-fifth annual convention. Our current method of electing officers has certainly not harmed the Association. It is probably the most democratic form of election, notwithstanding rather widespread opinions that selection of officer candidates is a cut-and-dried pre-arrangement. Through these twenty-five years, this Association has progressed steadily. There are no signs of senility, no permanent schisms, and no known dissension impending.

I should not, I feel, be carrying out my responsibilities as president of this Association should I not counsel an extremely cautious approach to this problem. Far better that this committee reach no conclusions than that it make recommendations which, if carried out, would prove to have been a cause contributing to a major membership decline of this Association.

Important as this subject is, I believe that your chairman might well secure the opinions of every past-president of this Association, and other members known to have first-hand knowledge of nomination and election situations. Opinions of district representatives should carry no particular weight unless their statements are the consensus expressed by the members of the district they represent.

If this report can be prepared and handed to your executive committee on or before October 1, 1939, the executive committee will have sufficient time to study the contents of the report, and to pass it on to district representatives who, in turn, should present the report before no less than two regular monthly meetings of their respective districts.

Yours very truly,
(Signed) HENRY A. LEY

HAL:lr:mw

CONVENTION STATISTICS

STATISTICS SHOWING PLACE AND YEAR OF ASSOCIATION ANNUAL MEETINGS, TOTAL MEMBERS IN ASSOCIATION, AND NUMBER ATTENDING MEETINGS

Place	*Year*	*Total Membership March 1*	*Active (Full) Members*	*Members at Meeting*			*Non-Members at Meeting*			*Total Registration*
				Active (*)	*Assoc.*	*Total*	*Men*	*Women*	*Total*	
Norman[1]	1916					50				
Tulsa[2]	1917	94	85			50				
Okla. City[3]	1918	176	160			125				
Dallas	1919	348	311							
Dallas	1920	543	454							
Tulsa	1921	621	536							
Okla. City	1922	767	631							
Shreveport	1923	901	712	150		181				
Houston	1924	1080	840	249	57	306				
Wichita	1925	1253	935	350		438			387	825
Dallas	1926	1504	1080	517		690	443			1133
Tulsa	1927	1670	1146	528 (404)	241	769	606	452	1058	1827
San Francisco	1928	1952	1282	212 (unan.)	49	261	62	63	125	386
Fort Worth	1929	2126	1496	621 (466)	212	833	270	351	621	1454
New Orleans	1930	2292	1683	448 (415)	90	538	150	292	442	980
San Antonio	1931	2562	1848	518 (unan.)	121	639	377	197	574	1213
Okla. City	1932	2558	1917	462 (354)	88	550	142	202	344	894
Houston	1933	2336	1800	429 (266)	77	506	245	270	515	1021
Dallas	1934	2043	1634	550 (141)	94	644	329	427	756	1400
Wichita	1955	1973	1591	458 (unan.)	65	523	386	272	658	1181
Tulsa	1936	2169	1732	677 (315)	114	791	536	520	1056	1847
Los Angeles	1937	2331	1885	378 (unan.)	33	411	424	227	651	1062
New Orleans	1938	2646	2082	602 (unan.)	120	722	428	556	984	1706
Okla. City	1939	2951	2306	710 (455)	121	831	642	385	1027	1858

[1] A meeting of geologists of the Southwest.
[2] The Southwestern Association of Petroleum Geologists.
[3] The American Association of Petroleum Geologists.
(*) Voters in annual election.

THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

CONSTITUTION AND BY-LAWS

(Adopted 1918 and amended 1921, 1922, 1923, 1925, 1927, 1928, 1929, 1930, 1932, 1933, 1935, 1936, and 1939)

CONSTITUTION

ARTICLE I. NAME

This Association shall be called "The American Association of Petroleum Geologists," incorporated under the laws of Colorado the 21st day of April, 1924, for a period of twenty (20) years.

ARTICLE II. OBJECT

The object of this Association is to promote the science of geology, especially as it relates to petroleum and natural gas; to promote the technology of petroleum and natural gas and to encourage improvements in the methods of exploring for and exploiting these substances; to foster the spirit of scientific research amongst its members; to disseminate facts relating to the geology and technology of petroleum and natural gas; to maintain a high standard of professional conduct on the part of its members; and to protect the public from the work of inadequately trained and unscrupulous persons posing as petroleum geologists.

ARTICLE III. MEMBERSHIP

Members

SECTION 1. Any person engaged in the work of petroleum geology or in research pertaining to petroleum geology or technology is eligible to active membership, provided he is a graduate of an institution of collegiate standing, in which institution he has done his major work in geology, or in sciences fundamental to petroleum geology, and in addition has had the equivalent of three years' experience in petroleum geology or in the application of these other sciences to petroleum geology or to research in petroleum geology or technology; and provided further that in the case of an applicant for membership who has not had the required collegiate or university training, but whose standing in the profession is well recognized, he shall be admitted to membership when his application shall have been favorably and unanimously acted upon by the executive committee; and provided further that these requirements shall not be construed to exclude teachers and research workers in recognized institutions, whose work is of such character as in the opinion of the executive committee shall qualify them for membership.

Active members alone shall be known as members.

Life Members

SECTION 2. The executive committee may grant life membership to members who have paid their dues and are otherwise qualified.

Associates

SECTION 3. Any person having completed as much as thirty hours of geology (an hour shall here be interpreted as meaning as much as sixteen recitation or lecture periods of one hour each, or the equivalent in laboratory) in a reputable institution of collegiate or university standing, or who has done field work equivalent to this, is eligible to associate membership, provided at the time of his application for membership he shall be engaged in geological studies in an institution of collegiate or university standing, or shall be engaged in petroleum geology; and any person who is a graduate of an institution of collegiate standing in which he has done his major work in sciences fundamental to petroleum geology or petroleum technology, and who has the equivalent of one year's experience in the application of his science to the study of petroleum geology, shall be eligible to associate membership, provided at the time of his application for membership he shall be engaged in investigations in the broader subject of petroleum geology and technology.

Associate members shall be known as associates.

Associates shall enjoy all the privileges of membership in the Association, save that they shall not hold office, sign applications for membership, or vote; neither shall they have the privilege of advertising their affiliation with the Association in professional cards or professional reports or otherwise.

The executive committee may advance to active membership, without the formality of application for such change, those associates who have, subsequent to election, fulfilled the requirements for active membership.

Election to Membership

SECTION 4. Every candidate for admission as a member or associate shall submit a formal application on an application form authorized by the executive committee, signed by him, and endorsed by not less than three members who are in good standing, stating his training and experience and such other facts as the executive committee shall from time to time prescribe. Provided the executive committee, after due consideration, shall judge that the applicant's qualifications meet the requirements of the constitution, they shall cause to be published in the *Bulletin* the applicant's name and the names of his sponsors. If, after at least thirty days have elapsed since such publication, no reason is presented why the applicant should be not admitted, he shall be deemed eligible to membership or to associate membership, as the case may be, and shall be notified of his election.

SECTION 5. An applicant for membership, on being notified of his election in writing, shall pay full membership dues for the current year and on making such payment shall be entitled to receive the entire *Bulletin* for that year. Unless payment of dues is made within thirty (30) days by those living within the continental United States and within ninety (90) days by those living elsewhere, after notice of election has been mailed, the executive committee may rescind the election of the applicant. Upon payment of dues, each applicant for membership shall be furnished with a membership card for the current year, and until such written notice and card are received, he shall in no way be considered a member of the Association.

Honorary Members

SECTION 6. The executive committee may from time to time elect as honorary members persons who have contributed distinguished service to the cause of petroleum geology. Honorary members shall not be required to pay dues.

ARTICLE IV. OFFICERS AND THEIR DUTIES

Officers

SECTION 1. The officers of the Association shall be a president, a vice-president, a secretary-treasurer, and an editor. These, together with the past president, shall constitute the executive committee and managers of the Association.

SECTION 2. The officers shall be elected annually from the Association at large by written ballot deposited in a locked ballot box by those members, present at the annual meeting, who have paid their current dues and are otherwise qualified under the constitution. Each candidate, when voted for as a candidate for the particular office for which he is nominated, shall be thereby automatically voted for as a candidate for the executive committee for one year, except that candidates for the presidency shall be automatically voted for as candidate for the executive committee for two years.

SECTION 3. No one shall hold the office of president for two consecutive years and no one shall hold any other office for more than two consecutive years except the editor who shall not hold office for more than six consecutive years.

Duties of Officers

SECTION 4. The president shall be the presiding officer at all meetings of the Association, shall take cognizance of the acts of the Association and of its officers, shall appoint such committees as are required for the purposes of the Association, and shall delegate members to represent the Association. He may, at his option, serve on, and may be chairman of, any committee.

SECTION 5. The vice-president shall assume the office of president in case of a vacancy from any cause in that office and shall assume the duties of president in case of the absence or disability of the latter.

SECTION 6. The secretary-treasurer shall assume the duties of president in case of the absence of both the president and vice-president. He shall have charge of the financial affairs of the Association and shall annually submit reports as secretary-treasurer covering the fiscal year. He shall receive all funds of the Association, and, under the direction of the executive committee, shall disburse all funds of the Association. He shall cause an audit to be prepared annually by a public accountant at the expense of the Association. He shall give a bond, and shall cause to be bonded all employees to whom authority may be delegated to handle Association funds. The amount of such bonds shall be set by the executive committee and the expense shall be borne by the Association. The funds of the Association shall be disbursed by check as authorized by the executive committee.

SECTION 7. The editor shall be in charge of editorial business, shall submit an annual report of such business, shall have authority to solicit papers and material for the *Bulletin* and for special publications, and, with the approval

of the executive committee, may accept or reject material offered for publication. He may appoint associate, regional, and special editors.

SECTION 8. The officers shall assume the duties of their respective offices immediately after the annual meeting in which they are elected.

ARTICLE V. EXECUTIVE COMMITTEE—MEETINGS AND DUTIES

Executive Committee

SECTION 1. The executive committee shall consist of the president, past-president, vice-president, secretary-treasurer, and editor.

Meetings and Duties

SECTION 2. The executive committee shall meet immediately preceding the annual meeting and at the call of the president may hold meetings when and where thought advisable, to conduct the affairs of the Association. A joint meeting of the outgoing and incoming executive committees shall be held immediately after the close of the annual Association business meeting. Members of the executive committee may vote by proxy on matters which require a unanimous vote.

SECTION 3. The executive committee shall consider all nominations for membership and pass on the qualifications of the applicants; shall have control and management of the affairs and funds of the Association; shall determine the manner of publication and pass on the material presented for publication; and shall designate the place of the annual meeting. They are empowered to establish a business headquarters for the Association, and to employ such persons as are needed to conduct the business of the Association. They are empowered to accept, create, and maintain special funds for publication, research, and other purposes. They are empowered to make investments of both general and special funds of the Association. Trust funds may be created, giving to the trustees appointed for such purpose, such direction as to investments as seems desirable to the executive committee to accomplish any of its objects and purposes, but no such trust funds shall be created unless they are revocable upon ninety (90) days' notice.

ARTICLE VI. MEETINGS

The Association shall hold at least one stated meeting each year, which shall be the annual meeting. This meeting shall be held in March or April at a time and place designated by the executive committee. At this meeting the election of members shall be announced, the proceedings of the preceding meeting shall be read, Association business shall be transacted, scientific papers shall be read and discussed, and officers for the ensuing year shall be elected.

ARTICLE VII. AMENDMENTS

Amendments to this constitution may be proposed by a resolution of the executive committee, by a constitutional committee appointed by the president, or in writing by any ten members of the Association. All such resolutions or proposals must be submitted at the annual meeting of the business committee of the Association as provided in the by-laws, and only the business committee shall make recommendations concerning proposed constitutional changes at the annual Association business meeting. If such recommendations

by the business committee shall be favorably acted on at the annual Association business meeting, the secretary-treasurer shall arrange for a ballot of the membership by mail within thirty (30) days after said annual Association business meeting, and a majority vote of the ballots received within ninety (90) days of their mailing shall be sufficient to amend. The legality of all amendments must be determined by the executive committee prior to balloting.

BY-LAWS

ARTICLE I. DUES

SECTION 1. The fiscal year of the Association shall correspond with the calendar year.

SECTION 2. The annual dues of members of the Association shall be ten dollars ($10.00). The annual dues of associates for not to exceed three years after election shall be six dollars ($6.00); for the second three-year period eight dollars ($8.00); thereafter, the annual dues of such associates shall be ten dollars ($10.00). The annual dues are payable in advance on the first day of each calendar year. A bill shall be mailed to each member and associate before January first of each year, stating the amount of the annual dues and the penalty and conditions for default in payment. Members or associates who shall fail to pay their annual dues by April first shall not receive copies of the April *Bulletin* or succeeding *Bulletins*, nor shall they be privileged to buy Association special publications at prices made to the membership, until such arrears are met.

SECTION 3. On the payment of two hundred dollars ($200.00) any member in good standing shall be declared a life member and thereafter shall not be required to pay annual dues. The funds derived from this source shall be placed in a permanent investment, the income from which shall be devoted to the same purposes as the regular dues.

ARTICLE II. RESIGNATION—SUSPENSION—EXPULSION

SECTION 1. Any member or associate may resign from the Association at any time. Such resignation shall be in writing and shall be accepted by the executive committee, subject to the payment of all outstanding dues and obligations of the resigning member or associate.

SECTION 2. Any member or associate who is more than a year delinquent (in arrears) in payment of dues shall be suspended from the Association. Any delinquent or suspended member or associate, at his own option, may request in writing that he be dropped from the Association and such request shall be granted by the executive committee. Any member or associate more than two years in arrears shall be dropped from the Association. The time of payment of delinquent does for either one year or two years may be extended by unanimous vote of the executive committee.

SECTION 3. Any member or associate who resigns or is dropped under the provisions of Sections 1 and 2 of this article ceases to have any rights in the Association and ceases to incur further indebtedness to the Association.

SECTION 4. Any person who has ceased to be a member or associate under Section 1 or Section 2 of this article may be reinstated by unanimous vote of the executive committee subject to the payment of any outstanding dues and obligations which were incurred, prior to the date when he ceased to be a member or associate of the Association.

In the case of any member or associate who has been dropped between the dates of January 1, 1931, and January 1, 1936, for non-payment of dues and who shall apply for reinstatement, the executive committee is authorized, at its discretion, to accept the resignation of such member or associate effective at any date during such period of delinquency, provided, the member shall pay all indebtedness to the Association incurred prior to the date of such resignation including a proper proportion of annual dues as shall be fixed by the executive committee. Such member or associate shall not be entitled to receive the *Bulletin* for any period subsequent to the date when his resignation became effective and prior to his reinstatement.

SECTION 5. Any member or associate who, after being granted a hearing by the executive committee, shall be found guilty of a violation of the code of ethics of this Association or shall be found guilty of a violation of the established principles of professional ethics, or shall be found guilty of having made a false or misleading statement in his application for membership in the Association, may be suspended or expelled from the Association by unanimous vote of the executive committee. The decision of the executive committee in all matters pertaining to the interpretation and execution of the provisions of this section shall be final.

ARTICLE III. PUBLICATIONS

SECTION 1. The proceedings of the annual meeting and the papers presented at such meeting shall be published at the discretion of the executive committee in the Association *Bulletin* or in such other form as the executive committee may decide best meets the needs of the membership of the Association.

SECTION 2. The payment of annual dues for any fiscal year entitles the member or associate to receive without further charge a copy of the *Bulletin* of the Association for that year.

SECTION 3. The executive committee may authorize the printing of special publications to be financed by the Association from its general, publication, or special funds and offered for sale to members and associates in good standing at not less than cost of publication and distribution.

ARTICLE IV. REGIONAL SECTIONS, TECHNICAL DIVISIONS, AND AFFILIATED SOCIETIES

SECTION 1. Regional sections of the Association may be established provided the members of such sections are members of the Association and shall perfect an organization and make application to the executive committee. The executive committee shall submit the application to a vote at a regular annual meeting, an affirmative vote of two-thirds of the members present and voting being necessary for the establishment of such a section; and provided that the Association may revoke the charter of any regional section by a vote of two-thirds of the members present and voting at a regular annual meeting.

SECTION 2. Technical divisions may be established, provided the members interested shall perfect an organization and make application to the executive committee. The executive committee shall submit the application to a vote at a regular meeting, an affirmative vote of two-thirds of the membership present and voting being necessary for the establishment of such a division. In like

manner, the Association may dissolve a division by an affirmative vote of two-thirds of the members present and voting at any annual meeting. A technical division may have its own officers, and it may have its own constitution and by-laws provided that, in the opinion of the executive committee, these do not conflict with the constitution and by-laws of the Association. The executive committee shall be empowered to make arrangements with the officers of the division for the conduct of the business of the division. A division may admit to affiliate membership in the division specially qualified persons who are not eligible to membership in the Association. Technical divisions may affiliate with other scientific societies, with the approval of the executive committee.

SECTION 3. Subject to the affirmative vote of two-thirds of the membership present and voting at an annual meeting, and with legal advice, the executive committee may arrange for the affiliation with the Association of duly organized groups or societies, which by objects, aims, constitution, by-laws, or practice are developing the study of geology or petroleum technology. In like manner and with like advice, the executive committee may arrange conditions for dissolution of such affiliations. Affiliation with the Association need not prevent affiliation with other scientific societies. Members of affiliated societies who are not members of the Association, shall not have the privilege of advertising their affiliation with the Association on professional cards or otherwise.

ARTICLE V. DISTRICT REPRESENTATIVES

The executive committee shall cause to be elected district representatives from districts which it shall define by a local geographic grouping of the membership. Such districts shall be redesignated and redefined by the executive committee as often as seems advisable. Each district shall be entitled to one representative for each seventy-five members, but this shall not deprive any designated district of at least one representative. The representatives so apportioned shall be chosen from the membership of the district by a written ballot arranged by the executive committee. They shall hold office for two years, their term of office expiring at the close of the annual meeting.

ARTICLE VI. COMMITTEES

Appointment and Tenure

SECTION 1. There shall be the following standing committees:

Business Committee
Research Committee
Committee on Geologic Names and Correlations
Committee on Applications of Geology
Committee for Publication
Finance Committee
Trustees of Revolving Publication Fund
Trustees of Research Fund

The president shall appoint all standing committees except the business committee for which provision is hereafter made. Members of all committees except the business committee shall serve for a three-year term, but in rotation, with one-third of the members being appointed each year. The president

shall designate the chairmen, annually, shall have power to fill vacancies, and shall notify the members of the committees of their appointment. The president may designate one or more vice-chairmen annually.

In addition to the aforesaid standing committees, the president shall appoint annually or semiannually a resolutions committee, and such special committees as the executive committee may authorize. Special committees shall be appointed for a term of one year. The president shall designate the chairmen of such committees.

Business Committee

SECTION 2. The business committee shall act as a council and advisory board to the executive committee and the Association. This committee shall consist of the executive committee, not more than five members at large appointed annually by the president, two members elected by and from each technical division, and the district representatives. The president shall also appoint annually a chairman and a vice-chairman, but neither of these need be one of those otherwise constituting the business committee. The secretary-treasurer shall act as secretary of the business committee. If a district or technical representative is unable to be present at any meeting of the committee he may designate an alternate, who, in the case of a district representative, may or may not be a resident of the district he is asked to represent, and the alternate, on presentation of such a designation in writing, shall have the same powers and privileges as a regularly chosen representative. The business committee shall meet the day before the annual meeting at which all proposed changes in the constitution or by-laws shall be considered, all old and new business shall be discussed, and recommendations shall be voted for presentation at the annual meeting.

Research Committee

SECTION 3. The purpose of the research committee is the advancement of research, particularly within the field of petroleum geology. The committee shall consist of twenty-four members unless a different number is authorized by the executive committee.

Committee on Geologic Names and Correlations

SECTION 4. The purpose of the committee on geologic names and correlations is to lend assistance to authors on problems of stratigraphy and nomenclature and to advise the editor and executive committee in regard to the propriety of the use of stratigraphic names and correlations in papers submitted for publication by the Association. The committee shall consist of fifteen members unless a different number is authorized by the executive committee.

Committee on Applications of Geology

SECTION 5. The object of the committee on applications of geology is to advise and promote ways and means for informing the general public on all phases of geology, particularly on the natural occurrence of oil and gas underground, the methods of searching for these substances, and the methods of exploiting them. The committee shall consist of twelve members unless a different number is authorized by the executive committee.

Committee for Publication

SECTION 6. The purpose of the committee for publication is to assist in securing desirable manuscripts for publication in the *Bulletin* or other publications of the Association. The committee may also assist in securing papers for delivery at the annual meetings. The committee shall consist of twenty-four members unless a different number is authorized by the executive committee.

Finance Committee

SECTION 7. The finance committee shall act as financial advisers to the executive committee. The committee shall consist of three members. If a member of the finance committee should be elected to the executive committee he shall resign from the finance committee and the president shall appoint a member of the Association to complete his unexpired term.

Trustees of Revolving Publication Fund

SECTION 8. Before any publication project shall be undertaken with the use of the revolving publication fund the approval of the trustees and the executive committee must be secured. There shall be three trustees. If a trustee should be elected to the executive committee he shall resign as a trustee and the president shall appoint a member of the Association to complete his unexpired term.

Trustees of Research Fund

SECTION 9. Before any research work may be undertaken with the use of money from the research fund, the approval of the trustees and the executive committee shall be secured. There shall be three trustees. If a trustee shall be elected to the executive committee he shall resign as a trustee and the president shall appoint a member of the Association to complete his unexpired term.

Resolutions Committee

SECTION 10. The resolutions committee shall be charged with the duty of presenting at the annual and semi-annual meetings resolutions expressing the Association's appreciation and thanks to those who have worked and contributed to the success of the meetings.

ARTICLE VII. AMENDMENTS

These by-laws may be amended by vote of three-fourths of the members present and voting at any annual meeting, provided that such changes shall have been recommended to the meeting by the business committee and provided that their legality shall be determined by the executive committee prior to publication.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 23, NO. 8 (AUGUST, 1939), PP. 1272-1279

STUDY GROUP REPORTS

PREFACE

With this issue of the *Bulletin* the editorial board of the A.A.P.G. is introducing a new series of informative articles entitled "Study Group Reports." We feel that it is eminently desirable to supply condensed information on practical petroleum geology problems and at the same time furnish information which is up to the minute in character.

One of the geological societies affiliated with the A.A.P.G. is the Houston Geological Society. They conceived the idea of establishing specialized groups to study certain definite problems and report on them at stated intervals of time. The subjects which were selected for special study are the following.

Surface geology	Geophysics
Subsurface geology	Structural geology
Paleontology	Mechanical well surveying
Stratigraphy	Evaluation
Sedimentation	Statistics
Paleogeography	Economics
Exploitation geology	Topography
Aerial geology	Electrical well surveying
Soil analyses	

A card was sent to approximately 300 members of the society, requesting each member to indicate which study group he preferred to join. A place was provided for first, second, and third choice. Subsequently, a steering committee of the society grouped the members according to their choice and selected a leader for each group. After studying their problem for two or three months, the conclusions reached by a certain group were put into brief form. These briefs were then published on mimeographed sheets and distributed.

With the permission of the Houston Geological Society and the members of the various groups involved, it is our privilege to republish some of these group reports. The first two appear in this issue of the *Bulletin*. After reading the reports, the editor is anxious to hear from as many readers as possible to get an expression of opinion regarding (1) the desire of the members to see more of these in print, and (2) the possibility of establishing other similar study groups in other parts of the country.

W. A. VER WIEBE

INTERPRETATION OF GEOPHYSICS[1]

REPORT OF HOUSTON GEOLOGICAL SOCIETY STUDY GROUP

The study group in the interpretation of geophysics held 7 meetings, some of which were attended by as many as 12 members. The leader, Paul Weaver, led the group with a series of fine lectures. The members of the group were at liberty to interrupt the lectures at any time to ask questions or offer discussion.

A. TWO TYPES OF GEOPHYSICAL PICTURES

Two different types of geophysical pictures were discussed: (1) where the anomaly is so strong and is measured on such physical properties that both

[1] Presented by Arthur B. Miller, Jr., at the meeting of the Society, February 23, 1939.

the kind of material causing the anomaly and the shape of the anomalous mass can be deduced, and (2) where the anomaly is small and caused by rocks whose physical properties differ but slightly from the surrounding rocks and therefore both the kind of material and the shape of the anomalous mass are difficult to deduce.

1. Three examples of the first type were discussed.

a. *Strong magnetic anomalies.*—There are only a few minerals which are para-magnetic; that is, show an effect in the earth's magnetic field, and of those only magnetite and ilmenite are found in any widespread quantity, except in certain very rare localities where franklinite, pyrrhotite, or some of the others occur in abundance. Therefore in practically every case a strong magnetic anomaly measures a large quantity of magnetite or ilmenite in some mass of rock. Magnetite and ilmenite are found in both basic and acid igneous rocks and in sediments derived from them but strong anomalies of great extent almost always show basic rocks, as both minerals favor basic rocks. Strong anomalies of small areal extent may be concentrations of magnetite in granite wash or other sediments or may be due to magmatic concentrations in igneous rocks. As there are no minerals which show an appreciable negative magnetic effect, magnetic lows are merely returns to base level between magnetic highs. However, Heiland thinks that negative anomalies are caused by overturning of magnetic rocks.

b. *Strong gravity anomalies.*—Salt is one of the most conspicuous of sedimentary rocks as to density. It has lower density than any other rock except recent unconsolidated sediments and some of the diatomaceous shales. Therefore, good-sized minimums can generally be attributed to salt masses and the shape of the mass can be fairly readily determined within certain limits unless two or more anomalies overlap. The basic igneous rocks are very conspicuous for their high density and most large maximums can be attributed to masses of basic igneous rock. More rarely granites or thick limestones in contact with young sediments may produce large maximums. Strong maximums of small areal extent may be lime or anhydrite caprock or the smaller-sized igneous intrusives.

c. *High-speed refraction seismic anomalies.*—Salt, limestone, anhydrite, granite, and basalt all have very high seismic velocities. When masses of any of these are in contact with other rocks, especially younger sediments, strong anomalies can be mapped by the refraction seismograph. The contrast between the velocity of the salt or other anomalous rock, and the velocity of the surrounding country rock, especially if the latter is unconsolidated, may be more than three to one. When the velocity of the anomalous mass is found to be about 14,000 feet per second, the rock is either salt, limestone, anhydrite, granite, or basalt. If the velocity is 16,000 feet per second or more, then the anomalous rock is either salt or granite. It may, however, be very old and very massive limestone or anhydrite, or it may be basalt, if the path is not close to the surface. The regional geology of the area will generally aid in the determination of the kind of rock which is causing the seismic anomaly. For example, in the Gulf Coast the mass would of course be a salt dome or its caprock. In West Texas it would probably be an igneous mass or massive limestone or anhydrite.

2. Three examples of the second type were discussed. That type is where the anomaly is small and caused by rocks whose properties differ but slightly from the surrounding rocks. These weak anomalies may be difficult to inter-

pret because the effect of the anomalous mass is masked by the effects of shallow formations which can not be computed separately. Also, weak anomalies must be centered in an area of monotonous geophysical character in order to be interpreted as it is very difficult or impossible to distinguish between two or more weak anomalies which are close together and to calculate anything definite about either one.

a. *Weak magnetic anomalies.*—Some sedimentary beds containing magnetite or ilmenite may be mapped at the outcrop by the magnetometer. This is because the magnetic mineral, being heavy and less soluble, is left behind during weathering and solution. However, where the bed containing excess magnetite is at considerable depth, it is very doubtful if the structure of the bed can be mapped, because even in the most favorable case the contrast is only slight between the magnetite-bearing sediments and the surrounding beds and the magnetic effect of still deeper basement basaltic or granitic rocks may be much greater and in the opposite direction.

b. *Weak gravity anomalies.*—Weak gravity minima standing alone can be used provided there are no serious surface effects on the instrument, but it is difficult or impossible to distinguish between a salt plug at great depth and a syncline or graben. Also weak maxima or minima are easily obscured by a strong regional variation of gravity from the basement.

c. *Weak reflection and refraction anomalies.*—The mapping of limestone, salt, or anhydrite masses that are surrounded by Paleozoic rocks is difficult because the velocity contrast of a path through them and one through the normal section is slight.

The same is true for deep salt domes, even in areas of Tertiary sediments, because the path to reach a deep dome must pass through so many beds that the path through the salt is only a small part of the total path. Therefore variations in the sedimentation and consequently in the velocity of these beds surrounding the salt may give more variation in the observations than does the presence or absence of salt in a small portion of that path.

Similarly with reflection shooting, the mapping of deep structures having small closures, shallow structures with very low relief, convergence of beds, and other stratigraphic traps, is difficult, because the contribution to the travel time of the seismic wave by the overlying beds, especially the surface (low velocity) beds, may mask the difference in depth to the beds in question.

It is the purpose of some of the recent new geophysical methods to find these structures which present weak anomalies by the older geophysical methods. It is believed, however, that more refined procedure by the old methods might have a chance to increase their success. For example, it was suggested that in reflection shooting, it might be possible to find the existence of a structure by studying the number and apparent spacing of reflections; such data might indicate local compaction, changes in sedimentation, or convergence of geologic section on structures, which dip computations on a phantom horizon did not show clearly.

B. GEOPHYSICS OF THE SOILS

Because of the importance of the properties of the shallow beds and the soil in affecting weak anomalies the concluding lecture was devoted to the physics of soils. It was mentioned that the physical characters of the soil depend mostly upon the climate, vegetation, and topography, rather than upon the parent material from which the soil was derived. This means that

in rough country with differences in cultivation, there is marked variation in the physical properties of the soil.

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MULTIPLE-OIL-ZONE COMPLETION

REPORT OF HOUSTON GEOLOGICAL SOCIETY STUDY GROUP

STUDY GROUP MEMBERS

OLIN G. BELL, leader, JOHN G. CAMPBELL, F. W. FREEBORN, JR., W. E. GREENMAN, JOSEPH HORNBERGER, LEIGH MASTERSON, DONALD E. MATHES, E. M. REED, LOUIS C. ROBERTS, FRANK C. ROPER, G. J. SMITH

I. INTRODUCTION

A systematic study of multiple-zone completions is of increasing importance with the necessity of deeper drilling and with the ever increasing costs of drilling and producing operations.

This study is undertaken, therefore, for the purpose of weighing the possibilities of multiple-oil-zone completions, both multiple-zone and multiple-reservoir completions, the various methods possible, relations to operating costs, ultimate recoveries *et cetera*, by considering hypothetical uses under various structural and sedimentary conditions.

For the purpose of this study, a distinction is drawn between a multiple-zone completion and a multiple-reservoir completion, A multiple-zone completion is defined as one whereby two or more oil zones of a unit reservoir are produced from one string of pipe and are produced at one and the same time. A unit reservoir is defined as a producing zone, or a group of zones, within a single geologic structure, interconnected by means of lensing or faulting or otherwise, and having common producing characteristics, a common gas-oil contact, and a common oil-water contact. A multiple-reservoir completion is defined as one whereby one or more oil zones in each of two or more unit reservoirs are produced from one well through one flow string and are produced at one and the same time.

It is recognized that in the early stages of development of a field the characteristics of the reservoir or reservoirs are not known. A reasonable amount of exploratory work is therefore necessary to obtain sufficient data for the regulatory bodies to determine what plan of future development is most suitable for the respective field.

While experience derived from development in other similar fields is indicative of the procedure to be followed in a new field, the detail characteristics of the field under consideration are far more important for determining its proper development.

Oil-pay thickness, intervening formations, relative position of various oil pays, gas-oil ratios, gravity of the oil, porosity, permeability and water encroachment in the various oil zones or reservoirs are individual items of vital importance. The individual importance of these various factors can be better defined by correlation with all other data on the field under consideration. Actual application of some of these items in certain areas is expressed in this report.

II. Applications

The following are some examples of multiple-oil-zone completion practices.

California

In California multiple-zone wells have been completed producing from three distinct zones aggregating 1,530 feet of sand and sandy formations, beginning at 2,370 feet and extending to 3,900 feet.

One of the methods of multiple-zone completions is as follows.

a. Setting a casing (large) on top of the Ranger zone and flowing that zone between the casing and a blank flow string

b. Setting a smaller string of pipe on top of the upper Terminal zone and flowing that zone between the casing and the tubing

c. Flowing the lower Terminal zone through the tubing

It is possible for each of these methods of flowing to be done by blank setting, setting with perforations, or direct setting of the screen or slotted pipe. Special precaution is necessary to obtain, as nearly as possible, perfect sealing of packers, cements, *et cetera*, in order to avoid inter-zone flowage of oil and water. A bad setting on one of the sands would, in most cases, be detrimental to the flowing of the other zone or zones, thereby necessitating immediate reworking of the well and resulting in additional expense. This extensive multiple-completion method has been found advantageous in order to separate the extreme variations in gravities during the flowing life of the well. Of course, multiple completion as discussed herewith is primarily concerned with reduced drilling costs by producing a maximum of three zones in one well.

Kansas

The Decorah ("Wilcox") sand production in Kansas is combined with production from the contiguous Arbuckle limestone. The rate of water encroachment in the Decorah sand is slow, whereas that in the Arbuckle limestone is rapid. Due to the ordinarily smaller area of Arbuckle limestone production, this horizon is exploited at edge locations, which would otherwise not have justified the expense of a well drilled from the surface.

The usual completion practice is to set the oil string of casing in the Trenton limestone which overlies the Decorah sand, and leave the hole open below the casing seat.

OKLAHOMA

In northern Oklahoma production from certain sands in the Hoover (Elgin) sand zone and contiguous underlying sands is segregated into certain divisions and produced jointly, depending on local conditions. These sands are generally of the gas-expulsive type. Water usually appears in these wells when in a semi-depleted stage but not in sufficient quantities to interfere with multiple operation. Some of these individual sands have a low ultimate yield per acre, either in the entire pool or at least in certain parts of the pool. This makes it desirable to combine the production from several sands; otherwise prohibitive drilling costs would limit adequate exploitation. Continuity of sands underlying the Hoover zone is, in some cases, uncertain. For this reason, production from lenticular sands with low ultimate yields can be made profitable by producing these sands in the same well with the Hoover sand.

The usual completion practice has been to set the oil string of casing on top of the first sand included in the local division of sands. Then, a string of pipe or liner is set on top of the lowest producing sand with slots opposite the other producing sands.

The "Wilcox" is a homogeneous sand, which has a wide areal distribution in Oklahoma. Where productive it is subject to an intensive or modified water drive. It has frequently been found desirable, in certain localities, to combine production from overlying limestones and sands in the Bromide formation, where present, with "Wilcox" sand production. The production from these Bromide zones is inclined to be erratic and subsequent water encroachment is either negligible or slower than in the "Wilcox" sand.

The completion practice is to set the oil string in the top of the Viola limestone, where present. The hole below the casing seat is left open. Occasionally some spotted production from the Viola limestone is included in the well with the Bromide and Wilcox sand production.

Where the upper portion of the Ordovician is absent on pronounced anticlinal structures, production has been obtained from the lower Simpson of the Ordovician formation. Separate producing zones have been combined, and in some places lower Simpson production, with production from the underlying Arbuckle limestone. The most rapid encroachment of edge water is generally in the Arbuckle limestone.

Where production is encountered only in the Arbuckle limestone, extensive oil-pay porosities occur. This requires deep penetration of this member.

The general completion practice in the Simpson formation and Arbuckle limestone is to set the oil string on the first producing member and leave the hole open below the casing seat.

In southern Oklahoma there are extensive sections of lenticular oil-producing sands in the Pennsylvanian on pronounced anticlinal structures associated with faulting, also in monoclinal areas there is some evidence of slight folding. These may be interpreted as depositional irregularities. These lenticular sands are usually segregated into various zones for identification.

Improved methods of drilling and completion practices have greatly facilitated the exploitation and have reduced the cost of exploiting these sands. The producing section is preferably penetrated with rotary to a safe depth above water level or water-bearing sands. The oil string is set and

cemented on top of the first oil zone, and a string of pipe with the bottom portion perforated, or a perforated liner, is set on bottom. Frequently the most active expulsive agent of oil from these sands is gas. Subsequent encroachment of edge water may be very irregular and slow. Wells in some of these areas are depleted without any evident water encroachment.

Occasionally large volumes of gas and troublesome quantities of water are obtained from intermediate sand lenses. Electrical logs will give the desired information as to the source of gas or water, and squeeze-cementing can be used successfully to eliminate these local conditions.

TEXAS

Recent practice limits the completion of an oil well to a unit reservoir, as herein defined. Where there is a thick producing section, the usual procedure is to drill the well to within a safe depth above the known water level, and set and cement the oil string on bottom. The lower part of the pipe is then perforated with a gun-perforator and the well brought into production. With decline in production, the pipe is perforated opposite upper productive sands. This procedure prevents thieving by upper sands, permits a conservation of the gas energy, prolongs the flowing life of the field, and adds to the ultimate recovery.

III. Proposed Multiple-Oil-Zone Completions

Where the main expulsive force in a unit reservoir is gas and there is no assured continuity of the several producing horizons, it is advisable to combine all producing horizons in one well. This is particularly desirable when the expected ultimate recovery from any individual zone would not justify its development alone. By combining several producing horizons in one well, the individual zone can be produced to a lower economic limit, particularly where local conditions make operating costs high.

In some fields there are extensive oil-producing sections of lenticular sands or porous limestones. These are interconnected and subject to a water drive with uniform oil-water contact. In this case, the entire producing section can be combined in one well. With subsequent depletion and water encroachment, the water can be reintroduced into the pay section at some logical point. This materially adds to the ultimate recovery of oil and facilitates the disposal of the salt water.

An upper oil-producing zone of the gas-expulsive type may be combined with a lower producing zone subject to a water drive. A satisfactory method can be used to plug off the lower zone when depleted.

Producing zones that are contiguous and subject to water drive can be combined where the lower zone has a much more rapid rate of water encroachment, if the intervening formation will offer a satisfactory seat for plugging off the lower zone when depleted.

Multiple completion, where conducted over a thick section with intervening shales, may offer some increased operating expense and possibly some damage to lower zones from mud sloughing into a well. This will require an occasional clean-out or bailing job. With the initial differential in pressure between various producing zones in an extended producing section, there may be some thieving by upper producing zones or porous, barren streaks. This should not result in any serious loss of oil as the differential in pressure is reduced.

In some sections of the United States, drilling is still permitted on close spacing of wells. This can only be justified where there is an extensive producing section or a series of producing zones that can be included in one well.

Multiple-oil-zone completion in some cases may interfere with later repressuring operations. The subject of multiple completion must be considered with the idea of obtaining the greatest ultimate profit from all anticipated operations.

IV. Conclusion

This paper does not intend to establish any precedent for multiple completion, since this problem has a varied application in each area or pool. The intention, however, is to stimulate thought on this interesting completion practice, which has yielded a greater ultimate profit to both the operator and the mineral owner. The low ultimate recovery from certain producing zones and the uncertain continuity of other producing zones might have precluded their exploitation individually. In the initial stages of development in a new field where multiple completion appears feasible, it is believed that the expectation of greater profits and the more effective drainage of all producing zones would be enough incentive for thoughtful consideration of multiple oil-zone completion.

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RESEARCH NOTES

ASSOCIATION RESEARCH COMMITTEE

A. I. LEVORSEN (1942), *chairman*, 221 Woodward Boulevard, Tulsa, Oklahoma

1940	1941	1942
HOWARD S. BRYANT	E. WAYNE GALLIHER	N. WOOD BASS
W. C. KRUMBEIN	W. S. W. KEW	MONROE G. CHENEY
EUGENE MCDERMOTT	JOHN C. MILLER	RONALD K. DEFORD
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E. H. SELLARDS	WENDELL P. RAND	BELA HUBBARD
THERON WASSON	F. W. ROLSHAUSEN	T. E. WEIRICH

The purpose of the research committee is the advancement of research within the field of petroleum geology. If members working actively in research on particular problems care to register with the research committee, the committee will be glad to aid them in any way it can and put them in touch with other men who are, or have been, working on similar or allied problems and can perhaps effect some integration of the research work of the Association. If the younger, or older, members of the Association, who are doing or preparing research for publication, will come to any member of the committee, he will be very glad to offer whatever advice, counsel, or criticism he can in regard to the research, its prosecution, or its preparation for formal presentation. The committee would be glad to have members formulate and present to it suggestions in regard to research problems and programs.

SURVEY OF GEOLOGY STUDENTS[1]

A. I. LEVORSEN[2]
Tulsa, Oklahoma

A survey of the college students in the United States who are majoring in geology was attempted as a part of the program of the research committee. Enrollment data were requested from 115 colleges and universities and to date sixty-seven replies have been received. These include nearly all of the larger geological departments and are uniformly distributed throughout the country. Following is a summary of the results obtained.

ENROLLMENT DATA AS OF THE MONTH OF JANUARY

		1938	*1939*	*Per Cent of Increase in 1939 over 1938*
Undergraduate—Majors in geology	Juniors	626	863	38
	Seniors	469	653	39
Graduate: Working toward degree of	Master	245	403	64
	Ph.D.	201	247	23
Estimated number of students leaving school in 1938 who entered petroleum geology		267		
Estimated number of students leaving school in 1938 who entered other lines of geology		220		

[1] Manuscript received, June 29, 1938.

[2] Chairman, research committee.

It is planned to continue this survey in succeeding years and make the results available at the annual meeting. Trends in enrollment may thereby be made available and should prove useful both to the prospective employer and to the person contemplating entry into the field of petroleum geology.

While this is probably the first survey of this kind made with particular reference to petroleum geology[3] and we may therefore not have a sufficient experience record to judge correctly, it would seem that a 40 per cent increase in one year is rather large. At any rate it presents a problem worth the careful thought of both the practicing petroleum geologist and the educator.

[3] For those interested, an extensive survey of petroleum engineering, mining, and geological schools has been made by William B. Plank, "Enrollment in U. S. Mineral Technology Schools Nears 10,000," *Mining and Metallurgy* (*Amer. Inst. Min. Met. Eng.*, New York, June, 1939), pp. 298–99.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 23, NO. 8 (AUGUST, 1939), PP. 1282-1284

Memorial

KARL SUNDBERG
(1891–1939)

The death of Karl Sundberg on February 3, 1939, took from the ranks of exploration geophysicists one of the internationally most widely known of the early pioneers in this profession.

Sundberg was born, June 26, 1891, in Mo, Ockelbo, Sweden. He attended the Royal Institute of Technology at Stockholm, Sweden, from 1910 to 1914, where he graduated as a mining engineer, February, 1915. During the following 6 years he served as a mining engineer in Sweden, and as a mine superintendent in Norway and in Finland. In 1921, having made already important contributions to the magnetic method of ore prospecting, he became attached to a mining company then engaged in a large-scale prospecting campaign in the Vaesterbotten province in North Sweden. Through the previous work by Hans Lundberg it had been shown that favorable conditions existed in this province for electrical prospecting methods. Sundberg now became the driving force behind the development of electromagnetic methods for ore prospecting in Vaesterbotten. Outstanding success followed this work from the very start, and although this may partly be accounted for by the favorable geological conditions, by the utilization of the latest developments in the then new radio technique, and by the foresight of the liberal financial backing, there is little doubt that Sundberg's ability and enthusiasm were the deciding factors. Among the many ore discoveries made through this work during the next few years the largest and most well known is the Boliden gold-arsenic ore, the largest gold ore discovery in Europe in the last 100 years. In 1924 Sundberg became associated with the Electrical Prospecting Company of Stockholm, which had been formed for the foreign exploitation of the electrical prospecting methods developed by Hans Lundberg and Karl Sundberg. He served as chief engineer in this company to 1929, during which time he spent 2 years in the United States as field manager, mainly for the geoelectrical structure work then being carried out by his company in Texas, Louisiana, and California. In 1930 he became managing director of the Electrical Prospecting Company. In 1934 he was elected managing director of the Swedish Diamond Rock Drilling Company of Stockholm, and later he became managing director of several associated companies. During the short time he served as manager of the Swedish Diamond Rock Drilling Company several new ideas in the core-drilling technique were successfully introduced, and under him this company expanded rapidly.

Sundberg joined the American Association of Petroleum Geologists in 1928 as an active member, sponsored by Sydney H. Ball, Paul Weaver, and H. E. Minor. Other scientific affiliations include active membership in the American Institute of Mining and Metallurgical Engineers, New York; the Institution of Mining and Metallurgy, London; the Swedish Academy of Engineering Science; Svenska Teknologföreningen, Stockholm; Geologiska Föreningen, Stockholm; and other Scandinavian societies. He was the author of a large number of publications, mostly on applied geophysics and prospecting, but including other articles, for example, on flotation.

He is survived by his wife, Gunhild S. Pehrson Sundberg; one son, now in his first year at the Royal Institute of Technology; one daughter; three brothers, one of whom is a civil engineer and another a metallurgical engineer.

Sundberg's optimistic outlook and inherent congeniality won him a great many friends literally all over the world. His optimism, while greatly stimulating to his co-workers, sometimes appeared to make him overrate his own strength and endurance. With all his vitality and extraordinary capacity for hard work he at last broke down; his heart had begun to feel the strain, and during the last year of his life he had several long periods of illness.

His death from heart failure at the early age of 47 came as a great shock to his many friends who keenly feel the loss of a great character and an outstanding personality.

HELMER HEDSTRÖM

STOCKHOLM, SWEDEN
June 3, 1939

IVAN MIKHAILOVITCH GOUBKIN
(1871–1939)

On April 21 died an outstanding Russian geologist, Academician, and the only member of the American Association of Petroleum Geologists from the Soviet Union.

I. M. Goubkin was born in a village of the Vladimir Government, Central Russia, son of a poor peasant family. After the usual 3 years in the village school he went to the County School, then to the Teachers Seminary of Kirjatch, the County seat, where he was granted a Government stipend of about $3 a month. The teaching career which he entered after graduation did not appeal to him, and he went, in 1895, to Petersburg; but because of lack of means succeeded only in being admitted to the Teachers Institute. Only at the age of 32, after several more years of teaching, did he achieve his ambition of becoming a mining engineer: in 1903 he entered the Petersburg Mining Institute.

Still as a student he did field and research work in the Maikop oil region. In 1910–12, after graduation, he did geological work in Kuban, Maikop, Taman, and later Apsheron oil fields. To him belongs the honor of working out the geology of Shirvan. By 1917 he became well known as a petroleum geologist. In that year the Government sent him to the United States of America to study the American oil industry. He returned to Russia in the beginning of 1918, after The Bolshevik Revolution. Since the ranks of scientists and qualified workers had been decimated by the revolution, Goubkin had his hands full. Most of the Russian oil fields in the south being in the hands of the Whites, he set to working out the exploitation of oil shale. After the Civil War he worked at the reclamation of the Baku, Binagady, Sulu-Tepe, and Khurdalan fields. The post-war development of Russian oil industry was due largely to him. Following the trend of the Soviet Government to concentrate industries in the deep interior, for strategic considerations, Goubkin bent every effort toward the development of the region between the Volga and the Urals. All new work in Emba, Azerbeijan, and Northern Caucasus is connected with his name. He was vice-president of the Geological Committee, chairman of the Supreme Geological Board, chair-

man of the Commission for Study of the Kursk Magnetic Anomaly, director of the Moscow Oil Institute, and editor of *Neftianoye Khoziaistvo* (Oil Industry). He became a member of the American Association of Petroleum Geologists in 1932.

I. M. Goubkin is also well known in the field of professional education. He is the author of approximately 150 scientific and technical books and papers, the last published dealing with the Russian oil reserves. He was first professor, then president, of the newly created Moscow Mining Academy. In 1929 he was elected to the Academy of Science, of which he became vice-president, in 1936. He was chairman of the XVII International Geological Congress held in 1937, in Moscow.

ANATOLE SAFONOV

ST. JOSEPH, MISSOURI
June, 1939

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 23, NO. 8 (AUGUST, 1939), PP. 1285-1286

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

KENNETH M. WILLSON, chief geologist of the Mid-Continent Petroleum Corporation, Tulsa, Oklahoma, has moved his headquarters to San Antonio, Texas.

IONEL I. GARDESCU, consulting geologist, addressed the Houston Geological Society, June 29, on "Miocene Production and Recovery from the West Columbia Field, Brazoria County, Texas," before returning to his native country, Roumania, in July.

RYCROFT G. MOSS, district geologist for the Phillips Petroleum Company, Wichita, Kansas, has moved to Evansville, Indiana, for his company.

REAGAN TUCKER, consulting geologist at Corpus Christi, Texas, and EARL S. POST have an article in the *Oil Weekly* of July 3, "McCampbell Holds Spotlight of South Texas District," illustrated by two electric-log sections and two subsurface structure maps.

P. CHARRIN, of the Schlumberger Well Surveying Corporation, has moved from Paris, France, to Houston, Texas.

The West Texas Geological Society, BERTE R. HAIGH, president, University Lands, Midland, Texas, has on hand extra copies of itineraries and maps of the following field trips that were sponsored by the Society: the Marathon Basin trip, May, 1936; the Franklin and Hueco Mountain (El Paso) trip, April, 1937; the East Side of Permian Basin trip, May, 1938; and the Van Horn Region trip, May, 1939. These are available at one dollar per copy.

HENRY A. LEY addressed the luncheon meeting of the West Texas Geological Society, at Midland, June 29, on the topics, "Current Affairs of the Association," and "Special Association Publications."

The West Texas Geological Society sponsored a field trip in the Van Horn, Texas, area on May 20 and 21. The first day was spent in visiting and studying the outcrops of the pre-Paleozoic Carrizo Mountain, Millican, and Hazel formations and the Permian and Cretaceous exposures on the western back slope of the Sierra Diablos. A discussion meeting was held that night at the headquarters hotel in Van Horn. On the morning of the second day, part of the group visited the Mica Mine district southwest of Van Horn and had an opportunity to observe some interesting sedimentary-igneous contact geology. The balance of the group indulged in an 1,100-foot climb on the northwest flank of the Beach Mountains, north of Van Horn, where the Van Horn-El Paso formations of Ordovician age were observed. The entire group joined at lunch. The schedule for the afternoon of the second day consisted of a visit to the Hazel silver mine and a visit to the unconformable Permo-Pennsylvanian contact in the vicinity of Marble Canyon, on the eastern fault-scarp of the Sierra Diablos. Officers of the Society are: BERTE R. HAIGH, president, University Lands; W. C. FRITZ, vice-president, Skelly Oil Com-

pany; and J. E. SIMMONS, secretary-treasurer, Continental Oil Company. The committee in charge of the trip were ROBERT E. KING, JOHN EMERY ADAMS, and JOHN HILLS. ROBERT E. KING was the principal guide.

F. W. BARTLETT, of San Antonio, Texas, recently accepted the position as chief geologist of European operations for the Socony-Vacuum Oil Company, of 26 Broadway, New York. His headquarters will probably be in The Hague.

C. F. BOWEN, formerly with the Socony-Vacuum Oil Company, at 26 Broadway, New York, may be addressed in care of A. E. Bowen, 255 First Avenue, Salt Lake City, Utah.

F. W. FLOYD, vice-president and manager of production of the Carter Oil Company, Tulsa, has moved to Caracas, Venezuela, to direct the operations of the Standard Oil Company of Venezuela.

M. H. BILLINGS, geologist and geophysicist, Houston, Texas, has gone to Manila to work for the National Development Company. H. FOSTER BAIN, formerly director of the United States Bureau of Mines, is advisor to the company.

BEN H. PARKER, of the Colorado School of Mines, Golden, Colorado, is working for the Argentine Government for a year.

JOHN H. WILSON, vice-president of the Independent Exploration Company, is in charge of the recently opened branch office of his company at 2015 Fort Worth National Bank Building in Fort Worth, Texas, and is district representative and staff geologist operating in North and West Texas, the Rocky Mountain region, and the Pacific states.

The Panhandle Geological Society, Amarillo, Texas, held a field trip, June 10 and 11, in New Mexico, from Roswell to Alamogordo for a study of the Paleozoic rocks and through the Lake Nogal and Capitan areas. H. G. WALTER, district geologist for The Texas Company at Pampa, Texas, and LEROY T. PATTON, Texas Technological College, Lubbock, Texas, conducted the trips.

PAUL H. BOOTS has changed his address from Gulf Exploration Company, 3 London Wall Buildings, London, to 226 Watertown Street, in care of Dr. J. A. Loomans, Waupun, Wisconsin.

J. WYATT DURHAM has returned from Medan, Sumatra, to 1108 West 53d Street, Seattle, Washington.

R. W. SHERMAN, consulting geologist, has moved his office from the Pacific Mutual Building to the Security Title Insurance Building, 530 West Sixth Street, Los Angeles, California.

JOHN F. DODGE, professor in the division of petroleum engineering, University of Southern California, Los Angeles, has been appointed technical assistant in the program of consolidating California oil deposits for United States fleet reserves.

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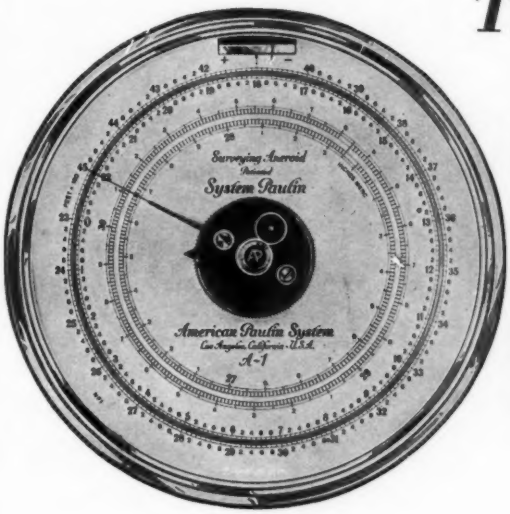

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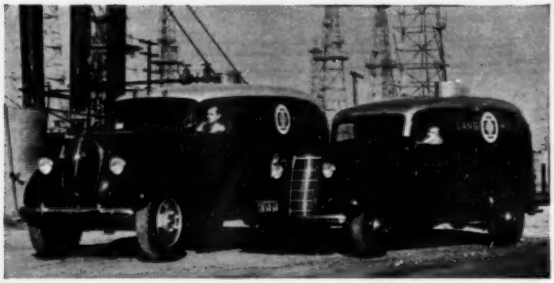

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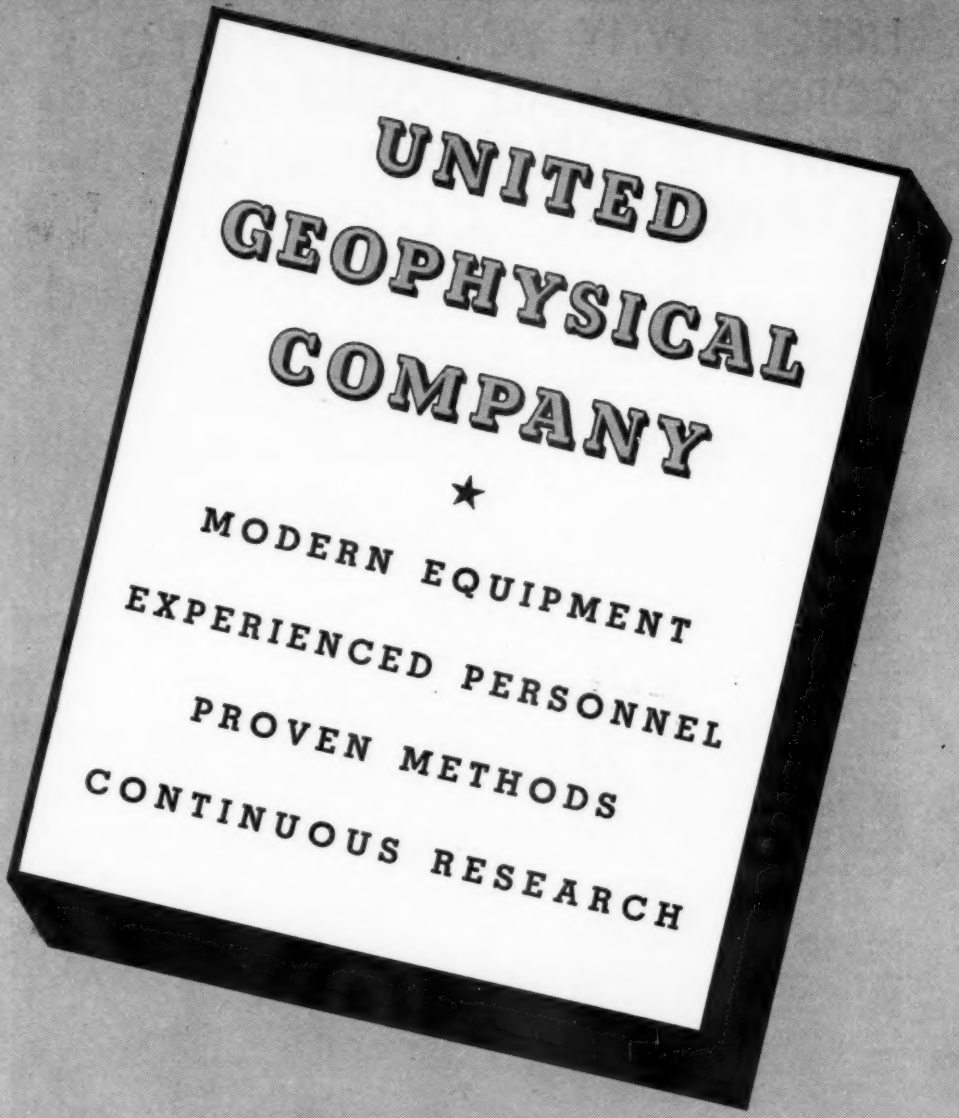

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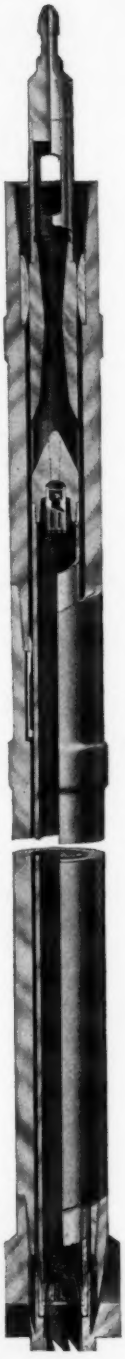

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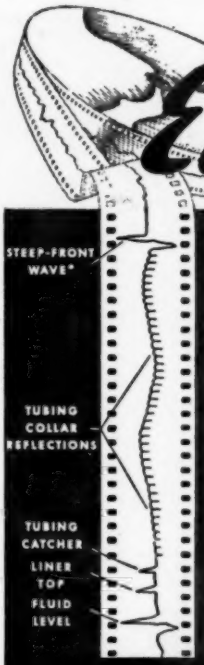

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